TRANSACTIONS

OF

THE OPTICAL SOCIETY.

Vol. XVIII. JUNE, 1917. No. 5.

Ordinary Meeting, 14th June, 1917.

Held at Burlington House, London.

Prof. F. J. CHESHIRE, President, in the Chair.

The Minutes of the previous Ordinary Meeting were read, confirmed and signed.

The following were balloted for and duly elected to the Society :—

As Members.

Frank A. Amsden, Inspector, India Stores Depôt, London.
F. F. S. Bryson, M.A., B.Sc., London.
Charles E. Heath, F.R.M.S., London.

It was announced that the undermentioned candidates had been approved by the Council for the ballot. The name of the proposer is appended :—

For the Class of "Member."

Harold Heaton Emsley, B.Sc., Glasgow (F. Cheshire).
William Gamble, London (R. S. Clay).
Robert S. Guilford, London (Conrad Beck).
Solomon Rennie, Glasgow (H. B. Doleman).
William Swaine, Glasgow (F. Cheshire).
Sidney John Underhill, London (F. Twyman).

The following paper was read by Mr. S. G. Starling, on "Aeroplane Compasses"; Dr. R. S. Clay described "An Optical Method for accurately dividing a Circle into Degrees."

Ordinary Meeting, 19th July, 1917.

Held at the Imperial College of Science and Technology, South Kensington.

Prof. F. J. CHESHIRE, President, in the Chair.

The Minutes of the previous meeting were read, confirmed and signed.

The following were balloted for and duly elected to the Society :—

As Members.

Harold Heaton Emsley, B.Sc., Glasgow.
William Gamble, Managing Director, Messrs. Penrose and Co., London.
Robert S. Guilford, Optician, London.
Solomon Rennie, Optician, Glasgow.
William Swaine, B.Sc., Glasgow.
Sidney John Underhill, Optician, London.

It was announced that the undermentioned candidates had been approved by the Council for the ballot. The name of the proposer is appended :—

For the Class of "Member."

J. Victor Armstrong, Liverpool (H. Dennis Taylor).
Rowland Arnison, London (F. Cheshire).
Selig Brodetsky, Bristol (A. E. Conrady).
Francis E. Collinson, London (F. Cheshire).
Charles Flint, F.S.M.C., F.I.O., London (H. E. Heath).
J. Guild, A.R.C.Sc., D.I.C., F.R.A.S., Teddington (F. Cheshire).
Arthur J. Hughes, London (F. Cheshire).
George Paxton, London (J. H. Sutcliffe).
Ernest Rheinberg, London (F. Cheshire).
Sydney George Starling, London (F. Cheshire).
Percy R. Warman, St. Leonards-on Sea (Max Coque).

The President gave an account of the arrangements which had been made for the formation of a Technical Optics Department at the Imperial College of Science and Technology, and made reference to the courses of Lectures on the Designing and Computing of Telescope Systems which were to be delivered.

Aeroplane Compasses.

By S. G. STARLING, B.Sc., A.R.C.Sc.,

Head of the Physical Department, West Ham Municipal Technical Institute.

Read and Discussed 14th June, 1917.

(1) CHIEF ERRORS.—The compass of an aeroplane flying on an "even keel" is subject to the same errors as a ship's compass, and these may be corrected in a similar manner; that is by the use of permanent magnets and soft iron correctors, and by "swinging" the aeroplane. These errors are due to iron and steel in the construction of the machine, and do not give rise to any new problems.

The error due to a *slight turn* is also similar to that experienced in the case of a ship's compass. It is transient, and should not be great in the case of a well designed compass. If the compass card is disturbed from its magnetic N. and S. position from any cause, a certain time elapses before it comes to rest again. This disturbance may be due to a variety of causes, amongst which the vibration, the centrifugal action of the heavier S. end of the card, and the carrying round of the card by the liquid in the bowl may be mentioned. Protection against vibration has been obtained in the case of the compasses by Messrs. Henry Hughes & Sons, by supporting the bowl on soft washers, maintaining the bowl in its normal position by means of spiral springs. This appears to be effective. That the disturbance due to centrifugal force on the heavier S. half of the card and the liquid in the bowl is small, even when these two disturbing forces are acting in the same direction, may be shown by holding a compass with the bowl south of the body and turning rapidly through 90°. In all the cases tried, the card is only disturbed to the extent of 1 or 2 degrees. The question of the settling down of the card due to a large disturbance from any cause is more important and is dealt with separately.

(2) DAMPING OF THE OSCILLATIONS OF A COMPASS CARD.—After a considerable disturbance of the card, some time must elapse before it is again at rest in its equilibrium position. As this question is of great importance in the large disturbances, treated later, to which an aeroplane compass is liable, it will be dealt with now.

A large magnetic moment means a rapid return; but if this is obtained by means of heavy magnets, a prolonged oscillation will result. A small

magnetic moment means a slow return, the motion being dead-beat or non-oscillatory. The objection to this is the low stability of the magnetic system, and the difficulty of determining when the card has reached its position of equilibrium, since it approaches this very slowly. If M be the magnetic moment of the magnet, I the moment of inertia of the system, H the intensity of the earth's controlling magnetic field, and K a couple due to friction or viscosity, assumed proportional to the angular velocity of the card, the equation of motion is,

$$I\frac{d^2\theta}{dt^2}+K\frac{d\theta}{dt}+MH\,\mathrm{Sin}\;\theta=0$$

when θ is the angle between the magnetic axis and the magnetic meridian. For simplicity, the motion when $\mathrm{Sin}\;\theta=\theta$ (approx.) is taken, so that

$$I\frac{d^2\theta}{dt^2}+K\frac{d\theta}{dt}+MH\,\theta=0$$

It is well known that the motion corresponding to this equation is oscillatory if $4\,IMH>K^2$ and dead-beat if $4\,IMH<K^2$, but the *shortest time of attaining rest* in the equilibrium position occurs when $4\,IMH\leqq K^2$. Most compasses are insufficiently damped, that is K is too small for this condition to be realised, and the card oscillates before coming to rest. Of the four quantities I, M, H and K, H is not under control, being the earth's field. Also, it is desirable to make M as great as possible, to obtain a strong magnetic control. Thus, if M is great it is desirable to make I (the moment of inertia) as small as possible, in order that rest shall be attained in the shortest time.

For this reason I have constructed several hollow steel magnets, having the sections shown in Fig. 1. These are so light that they also act as floats, and the metal is thicker at the central parts than at the ends.

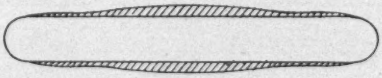


FIG. 1.

This thinning of the metal at the ends reduces the moment of inertia more than it does the magnetic moment, for two reasons. The moment of inertia of any mass varies as the square of its distance from the centre of rotation, while the magnetic moment due to any pole varies directly as the distance. Also the demagnetising effect is less than if the ends were thick.

The compass card constructed with these magnets comes to rest after a 90° displacement in 34 seconds, while the aeroplane compass shown comes to rest after a similar displacement in 47 seconds, and the ship's compass shown in 65 seconds. The new 1917 model aero compass comes to rest in 17 seconds.

(3) EQUILIBRIUM OF THE AEROPLANE COMPASS DURING A TURN.—The greatest error to which the aeroplane compass is liable is due to the banking which accompanies a turn of the machine. If no sideslip occurs, the resultant of the weight of the machine due to gravity, and the centrifugal force due to the turn, is at right angles to the base of the aeroplane. In this case a compass card, supported on a single point, would keep the position with respect to the bowl, which it had when the machine was at rest, and the tilt of the card is the same as that of the machine. It follows that the equilibrium of the compass card is no longer in the usual magnetic N. and S. position, that is, in the magnetic meridian. For each position, during a complete turn of 360°, the equilibrium position of the card must be calculated from the couples exerted by the horizontal and vertical components of the earth's magnetic field. This has been done elsewhere (see S. G. Starling, Philosophical Magazine, Vol. XXXII, Nov., 1916, p. 461), and the curves (Fig. 2) represent the deviation in

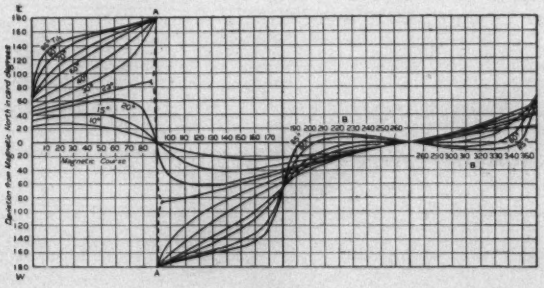


FIG. 2.

degrees from magnetic N. as would be seen by an observer on the aeroplane. Various tilts from 10° to 85° are given, and various courses from N. by E. to S. and W. again to N. It will be seen that for a tilt of 23°, that is, the complement of the magnetic dip, the card is in neutral equilibrium, when the course is magnetic E. This is to be expected since the card is now at right angles to the earth's resultant magnetic field. At tilts greater than 23°, the error reaches 180° when the course is E, and

is very great for all courses between 0° and 180°. Between 180° and 360° the error is much less, for a reason now to be explained. The disturbing factor is the vertical component of the earth's magnetic field (V) but if this were absent, there would still be considerable error. Putting V = O, the curves take the form given in Fig. 3. It is seen that the error is now quadrantal, and only reaches a value of 80° for a tilt of 85°. The

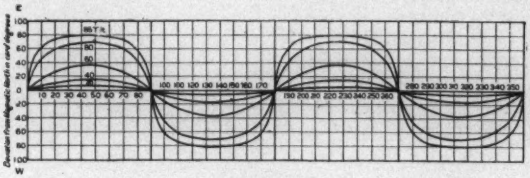


FIG. 3.

error due to V is semi-circular; for on any course between 90° and 270° in the southernly half of a turn, the component V tends to rotate the N. end of the card towards the W., and for the other half-turn towards the E. The result of this semi-circular deviation and the quadrantal deviation (Fig. 3) is to give the unsymmetrical curves of Fig. 2.

(4) DISTURBANCE IN TURNING.—The curves of Fig. 2 do not, of course, give the actual position of the card during flight, but they give the position towards which the card is urged at each instant during the turn. They give the positions of an ideal compass, which would instantaneously take up its position of equilibrium. Such an ideal compass would have great errors during the turn, but it would give correct bearings directly the turn was complete. An actual compass card possesses considerable moment of inertia, and the error during the first part of the turn would be less than that indicated by the curve, but since the effect of the disturbing couple is cumulative, the card would have acquired velocity before the end of the turn, and consequently overshoot this error, and would take some time to reach its equilibrium position on completion of the turn. The more sluggish the needle, the longer will this after effect last. In Fig. 4 three curves are drawn which are intended to indicate roughly the magnitude and duration of the error, during a turn from N. to E., A with a needle of small magnetic moment and long period of oscillation, B with a magnet of strong magnetic moment and short period, and C with a strong magnetic moment and approximately critical damping as indicated in (2).

(5) CORRECTION OF TILTING ERROR.—From the nature of the difference in effect produced by the vertical and horizontal components of the

earth's magnetic field (V and H), it is clear that if these are to be corrected by magnetic means, two different systems are necessary. I have suggested that the correction for V should be made by using a pair of magnets NS., NS. (Fig. 5), which produce a vertical magnetic field at the compass card, equal and opposite to V. They are then caused to tilt

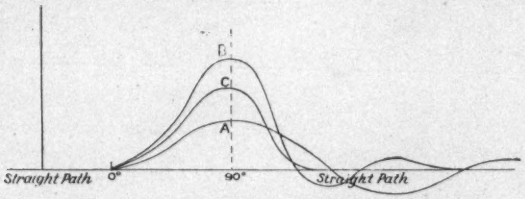


FIG. 4.

in the opposite direction to the aeroplane, and to an equal and opposite extent; or more strictly speaking, they are rotated with respect to the machine so that they remain vertical with respect to the earth. Their field then always eliminates V and the error caused by it.

The quadrantal error may then be corrected by masses of soft iron correctly disposed with respect to the compass and approached towards it as the tilt increases. This would give a correction of the right sign, but the magnitude must be determined by experiment.

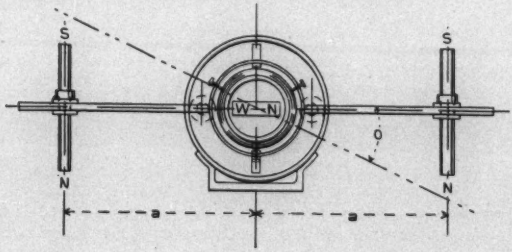


FIG. 5.

The movement of these correctors may be made by attachment to a stabiliser or by attachment to a tilt measurement device next described.

(6) TILT MEASURER.—When making a turn, the effective weight of every part of the aeroplane changes from its vertical direction, but at

the same time, it is increased by an amount depending upon the tilt. Thus, let m be the mass of the body A (Fig. 6) upon the aeroplane. Its weight due to gravity is $m\,g$. In turning, A experiences a centrifugal force $\frac{m\,v^2}{r}$ away from the centre of the turn, where v is the velocity of the body and r the radius of the turn. The resultant A B of the two forces $m\,g$ and $\frac{m\,v^2}{r}$ is the effective weight of the body upon the aeroplane,

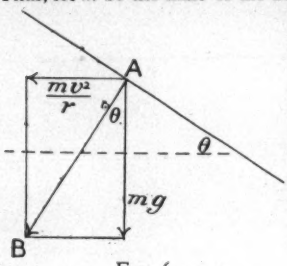


FIG. 6.

$$(A\,B)^2 = m^2\,g^2 + \frac{m^2\,v^4}{r^2}$$

or

$$A\,B = \frac{m\,g}{\mathrm{Cos}\,\theta} = m\,g\,\mathrm{Sec}\,\theta$$

where θ is a tilt.

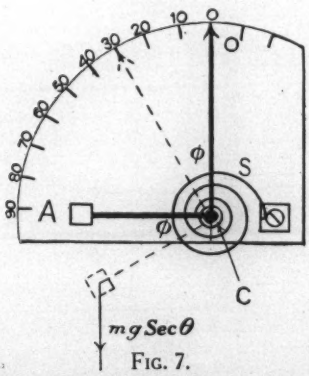


FIG. 7.

This principle may be applied by attaching the weight A to an arm C A (Fig. 7), the gravitational force being balanced by the couple due to a spiral spring S. A pointer C O moves over a circular scale and measures the tilt. During a turn the effective weight $m\,g$ Sec θ is at right angles to A C, and its turning moment about C is $m\,g$ Sec θ.AC.Cos ϕ where ϕ is the displacement of the spring. This is balanced by a couple $k\,(\phi + \phi_1)$, due to the spring, where ϕ_1 is the twist in the spring required to maintain A C in its horizontal position.

$$\therefore\ m\,g\,\text{Sec}\,\theta \times \text{A C. Cos}\,\phi = k\,(\phi + \phi_1)$$

$$\text{Sec}\,\theta = \frac{k}{m\,g\,\text{A C}}\,(\phi + \phi_1)\,\text{Sec}\,\phi$$

If ϕ_1 is large in comparison with ϕ, A C may be so adjusted that $\frac{k\,(\phi + \phi_1)}{m\,g\,\text{A C}} = 1$ in which case $\theta = \phi$ and the scale measures directly the tilt. If this adjustment is not made, the scale may still be constructed by experiment.

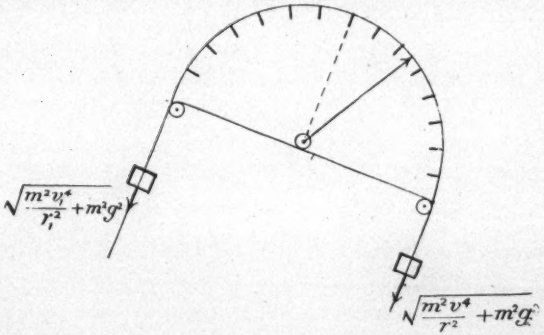


FIG. 8.

As a tilt measurer, this arrangement suffers from the defect that the pointer moves to the same side whichever the direction of the turn may be. The principle might be used for a differential tilt measurer, or an arrangement for controlling the correcting magnets of section (5) by making it of a differential form, since the side of the aeroplane on the outside of the turn has a greater velocity than that on the inside.

(7) ERROR ELIMINATING COMPASS.—The principle of increased effective weight is employed in the compass card, Fig. 9, in which the magnets, two in number, are pivoted so that they can rotate about a horizontal axis. One end of each magnet is weighted, and the magnet is maintained horizontal by means of a spiral spring. In taking a curve, the increased effective weight causes each magnet to tilt into a nearly vertical position, and so to diminish the magnetic moment of the card. Thus, in taking the curve, the error due to banking is reduced to a great extent if not eliminated, and on the turn being complete the magnets resume

their horizontal position. This removes the bump in the curves in Fig. 4.

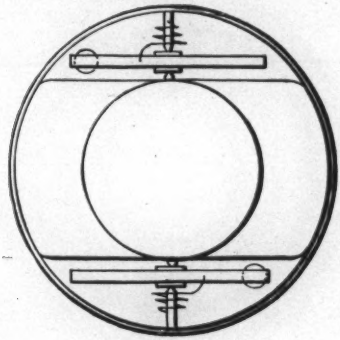


FIG. 9.

So far as I am aware, this form of magnet has not been given any facilities of trial, so that its behaviour in flight cannot be stated.

In conclusion, I must acknowledge my indebtedness to Mr. Arthur J. Hughes for inspiration in the work and unlimited assistance in the construction of the instruments, and to Messrs. Taylor and Francis for Figs. 2, 3, and 5 from the Philosophical Magazine.

DISCUSSION.

The PRESIDENT, in inviting discussion, said the Society would be most grateful for any suggestions from those present who had first-hand knowledge of the Service conditions which a magnetic compass must satisfy in the case of an aeroplane. In all matters dealing with munitions of war it was very difficult to find out exactly what the problem was which required solution, and it was practically impossible for scientists or manufacturers to proceed along the right lines in getting out new designs without such knowledge.

Major FILON said he was not in any sense a compass expert, and if anyone was present from the Compass Department of the Air Board he would like to hear his views. He would, however, like to ask Mr. Starling one question about the tilt indicator, a point in which he was very much interested, quite apart from the compass question. It seemed to him that the tilt indicator would indicate under other conditions than that of

merely going round in a horizontal plane. For example, when an aeroplane, after coming down, flattened out, then one had motion in a vertical curve, and therefore there was an additional centrifugal acceleration due to that, and it seemed to him the instrument would indicate on such an occasion. It might be rather upsetting if one's compass was thrown out of gear automatically by the tilt indicator (as had been suggested) in a case like that, and of course the same thing would happen in an exaggerated manner when looping the loop. The whole question of the northerly turn was a very sore point with pilots. The one thing he did know about compasses was that this was a matter on which no two pilots agreed.

Dr. LINDEMANN said he had been very much interested in hearing Mr. Starling's paper, and he had already read his paper in the *Philosophical Magazine*, which was the first really complete account of the equilibrium position of the needle at various degrees of bank. There were one or two points upon which he was not quite in agreement with the author; for instance, the question of the turning of the liquid. He, with others, had worked out the equations of motion of the card of the compass, assuming the liquid to rotate and assuming it not to rotate, and had found that the amount of rotation depended entirely upon which compass was used. With the 259 compass it was found that the liquid rotated completely as if it were fixed to the bowl.

Roughly speaking, aeroplane compasses were of two types as far as the northerly turning error was concerned; the one type showed a turn off North to the East as a turn to the West, the other indicated a turn to the East. If, when trying to keep a straight course in a cloud or in a fog, a turn to the East is shown by the compass as a turn to the West, the pilot turns still more to the West and the aeroplane ends in a spiral or even a spin.

He considered such compasses absolutely useless, and the only way, both mathematically and practically, of getting over the difficulty was by lengthening the period. The equation of motion contained four terms: (1) the inertia term, (2) the damping term, (3) the tilting term taking account of the errors which would take place on the magnetic equator, and (4) the term which takes account of the error due to the vertical component of the earth's magnetic force. The fourth term is divided by the square of the period, and is of the opposite sign to the inertia term; therefore, if the period is large, the last term is small and the compass indicates the turn in the right direction.

He thought the whole problem resolved itself into this—that the intersection of the gravitational and magnetic equipotential surfaces gave the E. and W. direction. When the aeroplane was accelerated, *e.g.*, on a turn, the compass could only show the plane containing the magnetic lines of force and the resultant of gravity and acceleration. Obviously

this plane was quite arbitrary. It seemed to him, therefore, that there was very little hope, by any mechanical device, of overcoming the difficulty. It was only possible either to make the inertia bigger, that was to say, to lengthen the period, or to make the magnetic control smaller, as Mr. Starling had shown. He must say he considered Mr. Starling's an extremely ingenious idea, and he was sorry not to be able to give him any information as to the actual result on an aeroplane. He had tried it himself, and it was unfortunately impossible to take any readings of value, because on an aeroplane one was practically always either climbing or gliding, one was seldom flying absolutely horizontally, and in the model he had tested the needle was always sticking at the top. He did not believe, however, the method would work, because on small angles of bank the variation of the downward force was very small. Although Mr. Starling had said that he thought it was only on large angles of bank that it really mattered, the northerly turning error was very strongly in evidence at *any* angle of bank, and if a turn to the left was made the compass indicated a turn to the right unless the period was sufficiently long. Most of the original work had been done by Captain Lucas, who was unfortunately killed last year, and it had been confirmed by himself and his colleagues in great detail. He did not know whether Mr. Starling had seen the papers and curves obtained.

The problem really to be solved was, he thought, to keep straight. No airman wanted to fly in one direction for a certain time and then to turn through some given angle by compass; he wanted to start on some definite course and keep straight on that course. As long as he could see the horizon or clouds he could keep on a straight line, if he had some point of reference by which to keep straight, and almost any compass was bound to be right. But when he got into a cloud he did not know whether the machine had banked or not, and the compass went wrong. And it was for that particular purpose that a compass was required with a long period. Very often a pilot wanted to climb through the clouds and to start in a northerly direction. He had met numbers of pilots who had told him they had come out of the clouds with a 45° or 60° bank, and a good many had told him they had come out upside down. This was entirely due to their not having a good compass or to their not using it properly. With a compass of a sufficiently long period, and prompt correction of any deviation from the course with the rudder, it was possible to fly through clouds or fog with absolute safety.

Major GRINSTED wished to endorse what Dr. Lindemann had said, particularly with regard to the statement that the most important thing is a rapid indication of any small change from a northerly course. It was not in the case of large banks that one was particularly troubled by the compass; it was in attempting to keep a straight course, where, if

the aeroplane made a small deviation, and it was not indicated by the compass, the pilot infallibly lost his way. There was one case, perhaps, in which the importance of coming to rest rapidly was greater than in the ordinary case of flying over land, and that was the case of sea-plane work. When out of sight of land, it was often necessary to fly by compass and keep dead reckoning. It was then essential that the compass should come to rest fairly quickly, otherwise the dead reckoning was not particularly accurate. But there, he thought, there was usually a fairly good horizon, so that the northerly turning error was not of such great importance, it always became possible to keep the aeroplane level, and in that case the short-period compass might be of greater use than one of longer period.

Mr. G. T. BENNETT said that many of them were anxious to improve their knowledge of the Air Compass, and they were grateful to the Optical Society for the opportunity afforded them that evening. Of course the behaviour of the Air Compass, especially in making a banked turn on a machine, was due to several contributory causes; the chief, as Dr. Lindemann had said, being the inertia effect, the damping effect of the liquid on the card, and the effect on the tilted needle of the line of the earth's force. He could not help thinking that the first of those, the inertia effect, hardly received enough credit. Mr. Starling was hoping, by abolishing temporarily during the turn the magnetic control on the needle, that inertia would cause the card to maintain its orientation. If the card were level no doubt that would be true; but in the case of a banked turn, especially a heavily banked turn, it would be anything but true. Let them consider inertia alone with no other effects. Suppose the card had no needle; suppose there was no damping at all; let the card be suspended from a frictionless pivot; then under those very attenuated and ideal circumstances it was possible to predict exactly what would happen in the case of a heavily banked turn. If the card was not rotating it would be found after the turn was complete that it was still not rotating, but it would nevertheless have turned round through an angle not very much less than the angle by which the course had changed. That was the result of isolating that cause; but of course in the case of a complicated dynamical problem such as this it was quite unreasonable to isolate any one cause, unless it was regarded as a merely partial indication. Mr. Starling had isolated one cause, and had done his dynamics in a peculiarly statical way. He had merely pointed out the position towards which the compass needle was tending all the time, and that was what he (Mr. Bennett) meant by complaining of Mr. Starling doing his dynamics in a rather statical way. Mr. Starling had not told them perhaps as simply as might be what the position was towards which the needle would be tending. On a tilted card, just as on

a level card, the needle tried to get as near the line of the earth's force as it could. And, indeed, the formula Mr. Starling gave in his *Philosophical Magazine* paper was nothing more than an analytical expression of that simple geometrical fact. He remembered in reading Mr. Starling's *Philosophical Magazine* paper he was somewhat puzzled by the angle selected as the one by which to measure the angle of deviation. The angle of deviation should be the difference between the true angle of the course and the angle as indicated by the compass, and the latter was nothing else than the angle from the north point of the card to the lubber-line. But Mr. Starling took as his deviation the angle from the equilibrium position of the needle to the line in which the magnetic meridian cuts the card. Now, if the deviation were annihilated it should be expected that the indication of the compass would be true. But would it be? The true angle of the course and the angle given by the compass would then both be measured from lubber-line to magnetic meridian; but one in the horizontal plane and the other in the tilted plane of the card. Thus the angles were different, and there would still be a deviation. But they were all very grateful to Mr. Starling for his excellent paper. It provided many opportunities of discussion. They were all more or less at present in the position of learners, and any criticisms that might be offered would, he was sure, be offered only in the true spirit of science.

Captain PIERRON said that it was interesting to him, and he was sure to many others present, to know the exact conditions under which the compass was being used at the Front in the present war. It was quite true that pilots used the compass simply when they were in trouble, and he thought everybody would agree with him that ninety-nine pilots out of a hundred, if they were in a position to use land-bearings, would use them. The compass was used when a man had lost his bearings, or could not see any. In both of those conditions he was not trying to bank, or to turn sharply; he wanted to fly as level as he could, and to keep his machine as steady as possible. So that very sharp banking or tilting was not interesting in war time. He was only speaking of land machines. There was only one case, practically, when a pilot really wanted his compass, and that was in hazy weather or if going up through clouds to fly over them afterwards, or diving down to come through them; he did not want to use his compass, but only to come through as quickly as possible. The use of the compass came in when flying by night, going on long distance bombing raids, or in misty weather. Under such circumstances, he had himself made extensive use of compasses; he had made sixty trips from London to Paris and back, and, as he had to perform those trips on appointed days, he very often had had to encounter very bad weather in crossing the Channel. That was where the compass was most useful, because one was flying practically due

magnetic N. on the way back from Paris to England by the shortest route, Gris-Nez-Dover. His personal opinion was that in such a case a slow-period compass was absolutely dangerous and the quick-period necessary. When caught in a haze nothing could be seen, the sea was grey, and one had no idea of one's direction at all. If, then, the machine started to turn it did not bank regularly, but more or less slipped; for some reason or other the machine ceased to follow its course, and before its failure to do so was detected it had made a complete turn on the opposite bank. That meant that practically the vertical component did not exist, and that was the reason why the disturbance was not so great as was thought. He had been using for six months a compass with a very short period, 14 or 13 seconds, and it had given extremely good results. In no case had he ever found any danger from the compass card pointing in the opposite direction in an involuntary turn. Of course, if he took somebody in his machine, he could, if he wished, make the card do it immediately, but practically, in the actual course of flying, he had never seen it occur. Of course, if the card was pointing in a wrong direction, by altering the course the machine would turn in a wrong direction and there would be a big side-slip, but this had never occurred with him. On the other hand, with a slow-period card he had been caught edgewise where he could not see any point which he could fix his eye on; there was then no sense of direction at all, and it was impossible for five minutes to steady the card so long as one could not see a spot in the sky, a boat in the sea, or any land-mark. Though according to all theory a long-period card was better, practically it was more dangerous in his own opinion, and he thought the opinion of practical pilots generally was tending towards that idea, and that nearly everybody liked the new compass better than the old ones.

Major BREMNER regretted that his experience of compasses was confined to their use on land, and did not extend to aeroplane compasses. His only experience of flying had lasted for about three minutes, and had ended in a spinning nose-dive.

Mr. ARTHUR HUGHES said he was only a compass maker, and he had not had many opportunities of testing compasses in the air. He certainly had observed the northerly turning error, and to an instrument maker, who was accustomed to work on the ground, the extraordinary effect which occurred in the air on the compass in turning was very interesting indeed. He thought Lord Kelvin, in dealing with the rolling period of ships, in one of the earliest papers, if not the most important, mentioned that the critical rolling period was 25 seconds, and he suggested at the end of that paper that it would be well to increase the period of the card to 30 seconds to avoid the rolling period of the ship. That was in effect

what had been done by increasing the period in the aeroplane compass, to aviod the critical period, or the turning period, or whatever it might be called. But he thought, although it was rather a dangerous thing to say, if Lord Kelvin were now alive he would endorse a quicker-period compass if he could have obtained it. At the time he introduced the ordinary light card, in the heavier cards that were in use in the Admiralty compasses the period was about 24 seconds, and it was because of that actual coincidence of the turn of the card with the rolling period of the ship that he suggested a longer period, and also because he could not get a quicker period. It was not possible to make a light card of 10 ins. diameter having a quicker period sufficiently far removed from the rolling period of the ship. In the paper in question Lord Kelvin had particularly said that in a liquid compass that period did not apply, and he thought what Mr. Starling had drawn attention to was particularly valuable because the liquid compass had, during the present war at any rate, come back to its own; it had come to be used practically entirely as the standard compass. It was of importance to note that what had to be studied in the liquid compass was the actual period of coming to rest. The period of the card, that was to say the one swing, did not matter so much; what mattered was the time required to bring the card to rest, and if the time of its coming to rest could be reduced sufficiently to be clear of the critical or the dangerous period of turning in the aeroplane, it was in his opinion very much better to do that than to extend the period. He had always understood from every flying man he had come into contact with that there were very serious objections on a straight course to the long period. In some cases no doubt it would act better than the quick-period compass, but for the ordinary work in the air the type which had now been evolved, having a card which came to rest in a very short time, was a very great advance. He believed, too, that it constituted a valuable practical addition to the work of Lord Kelvin himself, and that very shortly, in making compasses for ships' use, for navigation purposes, the object of study would be not so much the period of swing but the shortest time in which the card could be brought to rest. In conclusion, he would like to say that his connection with Mr. Starling had been a very interesting one. Mr. Starling had taken the matter up in a purely scientific way, and had worked it out, and had given a great deal of time and energy to it without any sort of recognition and practically without any assistance except that which he (Mr. Hughes) had been able to render him at odd moments. He considered it afforded an illustration of that combination between a scientific man and an industry which was so desirable, and which, if carried out more extensively, could not fail to have great effects.

AUTHOR'S] REPLY.

Mr. STARLING said that Major Filon had called attention to the fact that the instrument measures acceleration in the median plane of the machine, and he agreed with what he had said. He admitted that it was difficult to discriminate between the downward and upward acceleration, but the question was whether the tilt measurer did not remove a greater difficulty.

Dr. Lindemann had spoken with regard to the turning of the liquid. Of course, if a compass of a certain type was taken, and turned through 90°, there would be found in some cases a few degrees turn, but generally speaking the turn would be very small in the Kelvin adjustment, only a degree or two. In some of those which were nearly spherical, the amount of disturbance would be found to be extremely small. He did not quite see how in a much slower turn the liquid could have a very great disturbing effect. Dr. Lindemann also suggested that the longer period was much safer, but he did not tell them where to stop. Now the period could be made as long as was desired—infinitely long if necessary; the question was where they were to leave off. Dr. Lindemann had also referred to the reports of Captain Lucas, and he should be very glad to have the opportunity of seeing those reports.

Dr. LINDEMANN said they would be found among the reports of the Admiralty Committee on Aeronautics, and he had no doubt they could be made available for Mr. Starling's perusal.

Mr. STARLING, continuing, dealt with Major Grimsted's remark as to travelling at sea. He did not for a moment suppose that where an airman had land-bearings he would prefer to use a compass bearing. The whole idea was to supply some means for ascertaining the direction where there was no land-bearing.

Mr. Bennett had rather criticised his statical treatment of a dynamical problem, and he was afraid a good many people had blamed him for not putting into his paper what he had never intended to put in. He had not as a matter of fact attempted to deal with it as a dynamical problem but had merely taken it as a statical problem, and as a statical problem he thought it would give very important information. If it had done that he was quite content.

He had been most delighted to hear from Capt. Pierron that he agreed that the short period compass was best. This is a practical answer to Dr. Lindemann's suggestion of a long period. As he had already said, the difficulty was to make the period short; there was no difficulty in

making it long, and if there were no magnet at all it could be made an infinite period.

With reference to Mr. Hughes' remark on the Kelvin compass card, he himself thought there was very little doubt that Lord Kelvin, in avoiding the large force of vibration in the case of a ship would have chosen powerful magnets if he could have got them. But in those days a card had been designed with very small needles which had very small magnetic moment; the card was relatively of enormous weight, although made as light as possible. He thought if Lord Kelvin could have had more powerful magnets, even if it increased the moment of inertia, he would have done so, and in that way avoided resonance and at the same time have obtained very strong magnetic control.

The PRESIDENT said he was sure that after what they had heard they would all recognise the wisdom of Capt. Pierron's statement that a pilot never used a compass if he could possibly help it. In regard to the aeroplane, it appeared that the compass was simply used like the family doctor; it was never brought into use until it was absolutely necessary, and was then dispensed with at the earliest possible opportunity. If it was the fact that aviators could plunge into a cloud right side up and emerge the wrong side up without knowing it, all he could say was that he could quite understand the difficulty they had, under such circumstances, in using the compass at all.

An Optical Method for Accurately Dividing a Circle into Degrees.

By Dr. R. S. CLAY.

Read and Discussed 14th June, 1917.

It is very generally known that the image of the pupil of the eye seen through the hypotenuse face of a right angle prism and formed by two reflections in the other faces will be circular if the angle between those faces is correct, but will be shaped as in Fig. 1 if the angle is too small, or as in

Fig. 1.

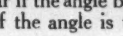
Fig. 2. 

Fig. 2 if the angle is a little greater than a right angle. It is not so well known that this is equally true if the angle between the two reflecting faces is 60°, 45°, 36°, 30° and so on, obtained by dividing 360° by the even numbers 6, 8, 10, 12, etc. This really means that if the mirrors accurately make those angles with one another, the final image formed by the successive reflections is in the same place whether the first reflection takes place in one mirror or in the other. For instance, if A and B (Fig. 3) are two mirrors inclined at an angle of 60° and C is an object between them, a series of reflections beginning in the mirror A will give the successive images C_A, C_{AB}, C_{ABA}. A second series beginning in mirror B will give C_B, C_{BA}, C_{BAB}. If the angle is exactly correct C_{ABA} and C_{BAB} will coincide. But if the angle between the mirrors be increased by an angle δ, the images will separate by an angular amount equal to 4δ. Thus it is possible to set a pair of mirrors at these angles to one another to an accuracy limited only by the resolving power of the instrument. (By a simple wooden model consisting of two discs rotating on a common steel spindle, each carrying one mirror, the images of a small circular aperture were projected on to a screen, and their coalescence shown when the angle between the mirrors was adjusted to be exactly a right angle.)

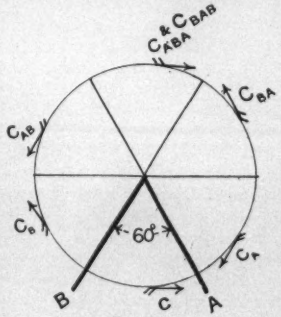


Fig. 3.

To use this principle to divide a circle a rectangular plane parallel glass is front-silvered, and is mounted on the circle to be divided with its silvered surface containing the axis of rotation of the circle and one edge coincident with that axis. We will call this the mirror A. A second similar mirror is mounted on a fixed arm, also with one edge as nearly as possible coincident with the axis of rotation of the circle, and in the first instance with its plane coincident with that of the first. We will call this the mirror B. These adjustments are made by means of an autocollimator carried on an arm which can be rotated about the axis of the circle. The two mirrors will be in one plane when the reflected images in the collimator coincide. The circle, carrying the mirror A with it, is now rotated approximately through 90° so as to bring the angle between the mirrors to a right angle. The final adjustment is effected by the autocollimator which is rotated through 45° so as to be about equally inclined to the mirrors. When the angle between the latter is correct, the reflected images seen in the collimator coalesce into a single one. In exactly the same way, the positions of the circle for which the angles between the mirrors are 60°, 45°, 36°, and 30°, are found. (At 60° and 36° the collimator has to bisect the angle between the mirrors or the images will not be in the field; at the other angles the collimator can be in any position.)

Each position of the circle found as above must be recorded in some way, depending on the object desired. If it is required merely to divide the circle, there would be a tool to draw the line, as on an ordinary dividing engine. If a master circle is required for the purpose of dividing others, a hole, either conical or cylindrical, may be drilled. Or a wheel with 360 (or some multiple or submultiple of 360) teeth may be made of steel with case-hardened teeth, and one of these teeth may be accurately corrected by a grinding wheel at each determined position.

So far the positions of the divisions 0°, 90°, 120°, 135°, 144°, 150°, have been found. To find other positions the mirror B is moved. For instance, when A has been set at the 90° as above, B is moved through 90° until it is once more in the same plane as A, and then A is moved as before; this will give the positions 180, 210, 225, 234, 240. By repeating this the positions 270, 300, 315, 324, 330 are found. And, in fact, it is easy to see that all divisions down to 3° can be obtained. Or, having once obtained the main divisions by this method, the repetition of the smaller divisions between them may be carried out by one or other of the ordinary methods, *e.g.*, by the use of a pair of microscopes.

For the final subdivision another property of a rotating mirror may be very conveniently made use of. When a ray of light is reflected by a mirror, a rotation of the mirror about an axis perpendicular to the plane of incidence will rotate the ray through double the angle that the mirror is turned through. If a ray is reflected to and fro between two mirrors,

and one of the mirrors is rotated about an axis perpendicular to the plane of incidence, the emergent ray will be rotated through an angle 2 n times the angle through which the mirror is turned, if n is the number of times the ray is reflected by the moving mirror; for instance, if the ray strikes the rotating mirror three times, it will be turned through an angle six times as great as the angle the mirror is turned through.

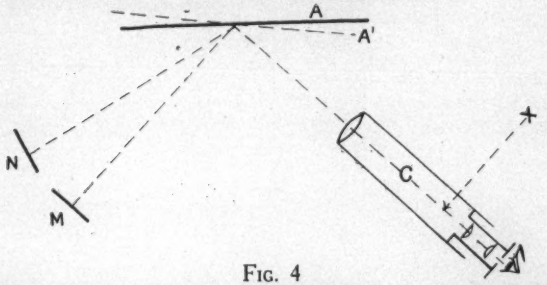


FIG. 4

To apply this principle, a mirror A (Fig. 4) is mounted as before on the circle. The light from an autocollimator C is reflected by A and falls normally on a mirror M by which it is returned in its path to C.

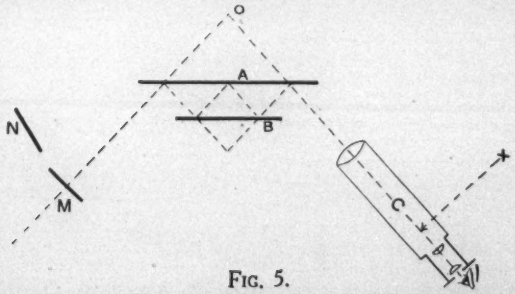


FIG. 5.

M is adjusted until the image coincides with the original scale in the autocollimator. The circle carrying the mirror A is now turned to A', through the angle which it is desired to divide, and a second mirror N is adjusted to return the light to the autocollimator. Next, without disturbing M or N, the mirror A is moved forward, and an extra mirror B (Fig. 5), carried on a

fixed support, is set up parallel to A. The distance from A to B must be half the distance from O, the centre of the divided circle, to A. A and B and the collimator are adjusted to return the light after reflection at M to the autocollimator. Then, without moving B or C, A is rotated until the light is returned to the autocollimator after reflection at N. A will have been moved through one-sixth of the angle between the faces of M and N, *i.e.*, one-third of the original angle which it was desired to divide. Thus the divisions can be carried out to single degrees.

The advantage of this method is that it is not a trial and error method, but an absolute one, and that the divisions are obtained directly to an order of accuracy limited only by the efficient resolving power of the instrument employed.

DISCUSSION.

Mr. S. D. CHALMERS said that some time ago he had had occasion to examine optical methods of dividing a circle into degrees, and a method somewhat similar to that indicated by Dr. Clay was among those considered; he had to decide what telescope would be required in order to get the necessary accuracy for a big circle such as was used in dividing engines. The makers were trying to get the original divisions to about 1-10th of a second; they did not get it, but that was what was aimed at. It was not practical to use a telescope of such a resolving power, but he believed it was quite possible actually to attain the degree of accuracy by a comparatively small modification of Dr. Clay's method. To observe the coincidence of the two images with sufficient accuracy, he thought it would be necessary to insert in front of the telescope two apertures, and to observe carefully the actual way in which the diffraction bands appeared on the overlapped images. In that way he believed it would be possible to check the two right angles and other submultiples of two right angles with very considerable accuracy indeed. He thought it would require a magnificent telescope, a very careful observer, and very delicate conditions with regard to temperature and otherwise before it would be possible to obtain anything like the accuracy obtained by the present mechanical methods.

Mr. T. SMITH thought that although Dr. Clay's method might be useful in cases where only tolerable accuracy was required, it would not work when very great accuracy was needed. There were several conditions necessary to be satisfied in a measurement of this kind before any high accuracy could be attained, and they were conditions which were usually entirely overlooked when new methods of measurement were proposed.

In the first place it was assumed that one had a perfect collimator; then it was assumed that the perfect collimator was perfectly focussed. Actually, those conditions were very difficult to realise. It was necessary to remember that if there was any error in focussing, so that the light was not exactly focussed upon the focal plane of the collimator, very important errors would result, which might be many times as great as those present when purely mechanical methods were employed. In general it might be said that if an angle was to be measured with an autocollimator, the beams defining the angle must not lie in the plane of the angle. In measuring the horizontal angles between beams emerging from two mirrors, the mirrors must be not side by side, but one vertically above the other. It had been shown by Guild in a paper read before the Physical Society, that errors in focussing, unless this condition was satisfied, rendered the apparent accuracy illusory.

When great accuracy was desired, and only part of the objective aperture was utilised by each beam, it was also necessary to make sure that the effects of zonal differences of aberration were eliminated.

The trouble involved in satisfying the conditions necessary to secure high accuracy in this problem was really so considerable that, in practice, it would be very much easier to make the adjustments entirely by mechanical means.

The PRESIDENT said he had been struck by the ingenuity of Dr. Clay's method, but he was rather afraid that Mr. Smith had taken the author of the paper a little too seriously. He did not for one moment suppose that Dr. Clay meant to suggest that his method was likely at any time during the period of the present war—which was his (the President's) main interest—to displace the engine-dividing apparatus already in existence. If any gentlemen among those present, working for the Ministry of Munitions, had any idea of scrapping the present methods and adopting those described by Dr. Clay, he would certainly urge caution.

AUTHOR'S REPLY.

Dr. R. S. CLAY writes:—

It is, of course, quite true, as Mr. Chalmers suggests, that a very large instrument would be required to obtain an accuracy of one-tenth of a second, and it is to be confessed at once that he had had no thought of attempting to obtain such an accuracy. On the other hand it is equally true that such an accuracy could only be of use, as Mr. Chalmers himself points out, with a telescope which has an objective 30 ins. in diameter.

Moreover, on a circle 4 ft. in diameter the divisions would have to be able to be read to nearly a ten-thousandth of an inch, which would require a high power microscope. Slight flexure or temperature variations of fractions of a degree would vitiate the readings. In other words, it is an impracticable order of accuracy. The best theodolites are divided to ten seconds, and may perhaps be accurate to this order. As a 4 in. telescope is more than sufficient to give this accuracy with this method, it should be good enough for all ordinary purposes.

In reply to the President he would point out that gun sights, compasses and other similar munitions instruments are only required to be accurate to one to five minutes, which is easily within the range of the method.

Mr. Smith's criticisms of the autocollimator are valuable, and it is of course obvious that care must be taken that it is not introducing errors. But these errors ought to be able to be kept within such limits that the method can be used for all ordinary commercial purposes. Whether it can be refined to the last limits will require further investigation. It is to be noted that any error introduced by the collimator is divided by two in the original setting of the mirrors A and B in one plane, and by at least four in the other positions.

It is, however, possible to avoid the use of the autocollimator altogether, and substitute an interference method for the original setting and for the angles 60° and 36° ; also for subdividing the angles ultimately. By this variation it may be possible to approach even to the accuracy suggested by Mr. Chalmers.

Dr. Clay adjusted the model for use with an autocollimator kindly lent by Mr. Newman, so that members were able after the meeting to appreciate the sensitiveness of the method.

Published by THE OPTICAL SOCIETY, 30, Victoria Street, Westminster, S.W. 1, and Printed at The Gresham Press, 6, West Harding Street, E.C. 4, London.

EXHIBITION

OF

WORKSHOP METHODS OF OPTICAL TESTING.

Held at King's College, Strand, on Thursday, 11th January, 1917.

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Exhibition of Workshop Methods of Optical Testing.

Held at King's College, Strand, on Thursday, 11th January, 1917.

THE Exhibition of optical workshop testing apparatus with which this catalogue deals was arranged by the Optical Society, at the suggestion of the Optical Department of the Ministry of Munitions, for the purpose of giving assistance to manufacturers in the production of optical munitions. The desirability and even necessity for the levelling up of workshop testing methods and apparatus had been realised. As will be seen by a study of the catalogue, the appeal thus made to manufacturers and others to assist in the securing of the desired end by exhibiting and describing their own particular methods for the benefit of the trade generally, met with a generous response.

It is to be hoped that the interchange of information, thus brought about, on a subject of such great importance will be continued. The creation, rather than the revival, of an English optical industry, to which we are looking forward, demands the introduction of the most modern scientific methods and apparatus to the workshop. If the exhibition of the apparatus set out in the following pages has in any way assisted in this end, its aim has been reached.

F. J. C.

T. H. BALL & CO.

Apparatus for Testing Signalling-Mirrors.

This comprises a simple but effective workshop system for testing the reflecting qualities of transparent polished plate glass before it is cut into circles, silvered, and completed for use in heliograph signalling mirrors, the object being to select glass suitable for use without being optically worked. By the means employed, it can be seen at once whether the glass is parallel and the surface perfectly plane.

A piece of plate glass of the first quality and the required thickness having been selected, it is placed on a large circle-cutting table which is then slowly revolved beneath a horizontally disposed diagram consisting of transverse lines and a double circle at the centre. The diagram

is fixed from 10 to 20 ft. high so that its reflection can be seen in the glass If the glass is not parallel, double lines are seen, and if it is not plane the image of the diagram is seen to be distorted. Thus it can be determined at a glance whether the glass can be used without being re-polished optically. When a perfect reflected image is obtained, the glass under test is equal to one which has been optically worked.

CAMBRIDGE SCIENTIFIC INSTRUMENT CO., LTD.

Screw-Measuring Machine.

The elements which can be directly measured for any given screw or tap are :—

(1) External diameter.
(2) Diameter at root of thread.
(3) Pitch.

To these should be added in the case of V threads :—

(4) "Effective diameter," *i.e.*, the mean diameter of the slant surface of the thread.
(5) Inclination of side of V.

The various inequalities to which screw threads are liable can also be detected.

The screw thread is viewed through a microscope, Fig. 1, which can

FIG. 1.

be set over to right or left, the amount of the inclination being read by means of an arc divided in half degrees. The field of the microscope is intersected by cross wires. The focussing adjustment of the microscope can be read micrometrically, the procedure being as follows:—The microscope is first focussed on the uppermost part of the thread. The outside diameter of the thread having been measured, the product of half of this diameter and the secant of the angle through which the microscope is set over gives the amount by which the microscope must be focussed down to obtain a correct view of the profile of the thread.

The screw under investigation is held in a self-centering split chuck, and the chuck itself is carried at one end of a cylindrical spindle supported in adjustable V's. The chuck spindle is turned by means of a milled head, the outer face of which is divided into 72 divisions of 5 degrees each.

In addition to the movements above described, there are two slow motions with micrometers. One of these enables the screw to receive accurately measured displacements in a direction perpendicular to its axis, and the other in a direction parallel to its axis.

For further details of the machine see "Engineering," Vol. LXXVI, November, 1903, p. 660.

Workshop Reading Microscope.

The instrument, Figs. 2 and 3, can be used to measure lengths up to 40 mm. directly to 0.01 mm. or by estimation to 0.001 mm. It consists of a microscope M clamped to a tube B, which is supported in a rigid frame, and can be traversed by the screw and milled head S through a distance of 40 mm. The instrument can be used with the axis of the

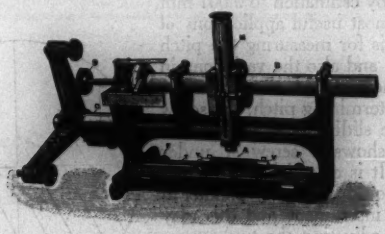


FIG. 2.

microscope either vertical, horizontal or inclined. Fig. 2 shows it with the microscope vertical, while Fig. 3 shows it being used with the micro-

scope horizontal, in which position it is supported on a tripod base with levelling screws. The microscope M, which can be clamped at any point on the tube B, is fitted with an achromatic objective and suitable eyepiece with cross lines. For the focussing of the microscope Lucas's Patent Slow Motion mechanism is used; this gives a smoother movement than the ordinary rack and pinion, and is entirely free from backlash. For supporting the object under examination a small sliding table T resting on geometric fittings is provided. This is fitted with aligning adjustments controlled by the screws F, F. Small V blocks on geometric supports are also provided to take screws, cylinders, etc.

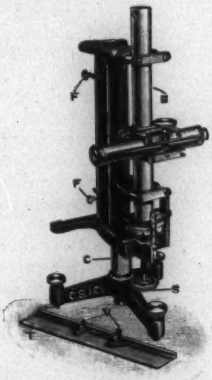


FIG. 3.

The instrument is used as follows:—The object under examination is supported on the table T, and the microscope set so that the intersection of the cross wires coincides with one extremity of the length to be measured. The reading of the micrometer head is taken and the microscope is then moved by turning the milled head S until the other extremity of the length under examination coincides with the intersection of the cross lines. The difference of the readings on the micrometer head in the two positions gives directly the required length. Since the screw has a pitch of 1 mm. and the micrometer head is divided into 100 parts each approximately 1.7 mm. in length, readings can be obtained directly to 0.01 mm. or by estimation to 0.001 mm.

One of the most useful applications of the instrument is for measuring the pitch of small screws and also the variations in pitch from one part of the thread to another. In determining pitch, the screw is rested on the sliding blocks V, V (see Fig. 2, which shows a screw A under examination). It is essential that the axis of the screw should be exactly parallel to the axis of the instrument, and this may be secured by adjusting the two screws F, F. The microscope is set so that the intersection of the cross lines coincides with the apex of one of the screw threads, and the reading of the micrometer head is

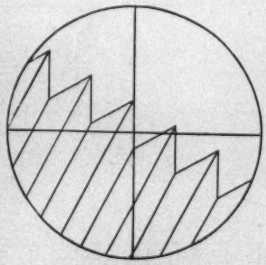


FIG. 4.

taken. The traversing screw is then turned until the point of intersection coincides with the apex of the next turn of the thread, the pitch being then given by the difference of the two readings on the micrometer head. The addition of a goniometer eyepiece to the microscope enables the instrument to be used also to determine the angle of V threads. For this purpose the microscope is set so that one of the cross lines coincides with one side of the V (see Fig. 4) and a reading is taken on the divided circle of the goniometer eyepiece. The eyepiece is then rotated until the cross line coincides with the other side of the V. The angle through which the eyepiece has been rotated, as shown by the difference between the two readings on the divided circle, gives directly the angle of the V.

S. D. CHALMERS, M.A.

Apparatus for the Measurement of Curvature of Test Plates of Radii less than 60 mm.

The apparatus consists of a measuring microscope with which readings can only be taken in one direction. The eyepiece has two fine parallel cross-wires. A special target, as shown in the upper part of Fig. 5, consisting of two parallel black lines about 10 mm. long and ½ mm. wide

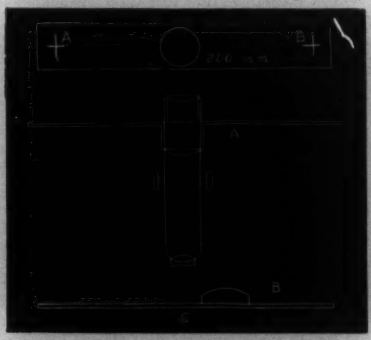


FIG. 5. A—ATTACHMENT. B—TEST SURFACE. C—MOVING STAGE.

on a white ground, is attached to the eyepiece of the microscope. These lines are about 200 mm. apart. The target is so adjusted that the lines

are symmetrical with regard to the microscope tube, and the line joining their centres passes through the axis of the microscope and is parallel to the direction of traverse of the microscope.

One test plate is placed on the stage, and the image of one target line is sharply focussed. The microscope stage is moved to bring the image of the target line on the cross wires of the eye-piece, and a reading R is made. The other target line is then brought on to the cross wires, a reading R_2 is made, and the difference d_1 between the two readings is noted.

The second test plate is measured in the same way, and the difference d_2 is obtained. The radius of the test plates is given by $R = (d_1 + d_2)\,k$, where k is a constant for the instrument, the exact value of which depends on the separation of the two lines and their distance from the focus of the microscope.

For further details see Trans. Opt. Soc., Vol. XVI, 1915-16, p. 169, "Laboratory Measurements for Workshop Purposes," by S. D. Chalmers.

Apparatus for Measuring the Curvature of Shallow Curves and for Measuring Differences of Curvature.

The apparatus which employs the Newton's Rings method in monochromatic light is essentially that described before the Optical Society.

For details of the apparatus and method of using it, see Trans. Opt. Soc., Vol. XVI, 1916, p. 171.

Instrument for Testing the Angles of Prisms.

The principle of this instrument was described before the Optical Society in conjunction with Mr. Ryland in 1905. (Trans. Opt. Soc., Vol. VI, 1904-5, p. 34.)

The instrument is used to measure the errors in the right-angles of binocular prisms, the difference between two nearly equal angles of any prism and the errors of pyramid in prisms. The apparatus consists of an auto-collimating telescope with a plane surface normal to the axis against which the prism can be held. Light diverging from a brightly illuminated slit falls on the prism and is reflected back as two slightly inclined beams. The angle between the two reflected beams is observed by means of a scale in the eye-piece and the value of the angle so obtained, divided by $4n$. (n is the refractive index of the prism) gives the error in the right angle.

For further details see Trans. Opt. Soc., Vol. XVI, 1915-16, p. 174.

Test Plates.

(*a*) An illustrative set of curved test plates to show the various defects of optical surfaces, viz., incorrect curvature, bad figure and bad surfaces.
(*b*) A set of plates illustrating different standards of work.

CHANCE BROS. & CO., LTD.

Wave Plate for the Rapid Approximate Assessment of Double Refraction in Glass.

This plate consists of laminae of mica (or other suitable mineral) cemented between glass plates or lenses. The mica is of such a thickness as to give a phase difference in the two beams of one wave for sodium light. This plate, therefore, gives approximately the sensitive first order violet colour between crossed nicols. The use of such a plate is well known for the detection of weak double refraction in rock slides, etc. It is here put forward as giving a ready method of measuring approximately the extent of double refraction in glass specimens when these are examined in conjunction with the plate between crossed nicols. According to the orientation of the specimen, double refraction is made evident by the change of the violet colour to a tint of a lower or higher order. Each tint is due to a definite phase difference produced by the double refraction of the glass, and hence an estimation of the tints exhibited gives a measure of the phase differences produced in a beam on passage through the glass. When crossed nicols alone are used, weak double refraction up to nearly $\frac{1}{2}\lambda$ for sodium light is made evident by the appearance of white patches of varying brightness. If the appearance of any such white light is taken as a test for imperfect annealing, the sensitiveness of the test depends very greatly on the intensity of the original beam, and with an intense source of light the test is very severe and detects traces of double refraction which are quite harmless in optical instruments. The colours given in conjunction with the wave plate are, on the other hand, independent of the intensity of the light.

It will further be found that examination of specimens against a violet background has a very important advantage when the specimens have not been optically worked, *e.g.*, rough moulded plates of optical glass, laboratory and other glassware. In such cases the reflections from the irregular surfaces tend greatly to mask and become confused with the appearance of white light between crossed nicols, but do not affect the change of tint produced with a wave plate. A plate or prism which has been very roughly ground on opposite sides may be readily examined

if a few drops of a suitable liquid of about the same refractive index are smeared on the two surfaces.

To obtain a field of uniform violet colour, the wave plate must be used in parallel or nearly parallel light, otherwise the varying length and obliquity of path through the mica cause a variation in the interference colour.

The light from the polariser will be sufficiently parallel if the source of light does not subtend at the eye an angle greater than that of an area 8 in. square at 5 ft. from the eye. This solid angle is sufficiently great in most cases, especially for the examination of prisms which are to be used in parallel light. If however it is desired to be able to work with a beam converging to a greater solid angle, steps must be taken to collimate the light before it passes through the plates.

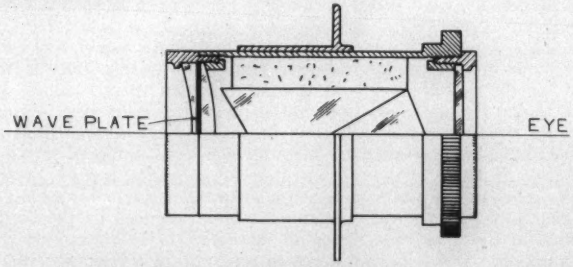


FIG. 6.—WAVE PLATE, CEMENTED BETWEEN COLLIMATING LENSES, MOUNTED WITH NICOL ANALYSER.

In the above form of apparatus, in which the wave plate is used at the eye end, collimation is most conveniently effected by the arrangement of lenses suggested by Mr. Twyman, of Adam Hilger, Ltd. The light, which is converging to the eye, passes first through a concave lens of about 3 in. focus, Fig. 6, then through the plate, and afterwards through a convex lens of similar focus to restore convergence to the beam. These lenses may conveniently be plano-concave and plano-convex, preferably flint, with the wave plate cemented between them.

To take full advantage of this arrangement the polarising plate should be bent to such a radius (about $1\frac{3}{4}$ times its distance from the eye) that all the rays coming from the plate to the eye leave at the polarising angle of reflection. A large field, practically uniform in colour, will then be obtained with the wave plate.

The apparatus exhibited consisted of an ordinary arrangement of

polariser and analyser, the latter being mounted in conjunction with the wave plate. A large, nearly uniform source of light was obtained by a number of electric lamps placed behind a ground glass screen. The light was then polarised by reflection at a black plate, passed through the specimen and thence through the wave plate and nicol into the eye.

In order to set up the apparatus in correct adjustment, the wave plate should be removed and the analyser set to give extinction. The wave plate should then be added and rotated to give extinction. This position should be marked, as it may be desirable at times for comparison to place the plate in this position to give the effect of crossed nicols. The wave plate will normally be used in the position obtained by rotating it in either direction about 45° from the extinction position, *i.e.*, until a bright indigo field is obtained.

DR. R. S. CLAY.

Instrument for Measuring the Refractive Index of a Liquid.

The essential part of this instrument is a combination of two similar right-angle prisms of highly refractive glass, which have acute angles of 45° ; a drop of the liquid to be examined is placed on the hypotenuse of one of the prisms, and the hypotenuse of the other prism is then placed upon that of the first, thus forming a rectangular block. The method employed is that used in the Abbe Refractometer.

For further details see "Treatise on Light," by R. S. Clay, p. 136.

Instrument for Measuring the Refractive Index of a Transparent Solid.

For details see Trans. Opt. Soc., Vol. XVII, December, p. 93.

Apparatus for Testing Binocular Glasses.

The apparatus consists essentially of four parts :—a fixed collimator, a carriage upon which the instrument to be tested is placed, a low power telescope, and a base.

Taking these in turn—

(*a*) THE COLLIMATOR, C, Fig. 7, consists of a "Rapid Rectilinear" photographic lens—of about 7 in. focus, with a surface ruled in millimeter squares in its focal plane. This is illuminated from behind with a ground glass behind the ruled glass to distribute the light. The lens, ruled surface, ground glass, and light are mounted in a tube.

(*b*) THE CARRIAGE stands on three legs forming an equilateral triangle. Two of these *A* slide in a V in the base of the instrument, and the third rests on a flat. This gives it a motion parallel to itself, and at right angles to the optic axis of the whole instrument. These legs are part of a casting

which is screwed to the under side of a board *D* about 9 in. square. To this board, at the front edge, is hinged a second board *E*; and to the back edge of this is a hinged third board *F*.

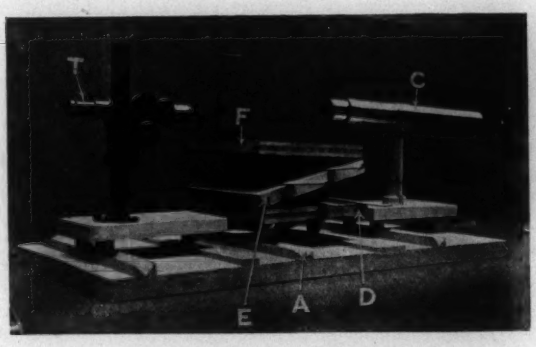


FIG. 7.—COMPLETE INSTRUMENT.

(c) THE TELESCOPE, *T*, has an objective about 1 in. diameter and 6 in. focus, and a magnification of about four, and has a Ramsden eyepiece. In the focal plane of the objective is a graticule with a horizontal and a vertical line. (Fig. 8.) The vertical line also has two short lines cutting it as shown, and they are so spaced that when the telescope is pointed directly at the collimator, *i.e.*, with no binocular between—the apparent distance apart of the lines in the image of the collimator graticule as seen in the telescope, is exactly equal to the distance between the horizontal line and the short lines cutting the vertical line. If now a binocular is introduced between the collimator and telescope, so that the light from the collimator enters the eyepiece of the binocular and issues from its objective, then the image seen in the telescope will be smaller, and the number of lines in the telescope will give the magnifying power of the binocular.

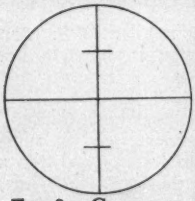


FIG. 8.—GRATICULE.

The telescope is capable of movement parallel to itself, both horizontally and vertically.

The horizontal movement is provided for by a stand with three legs,

two sliding in a V in the base, and the third on a plane, and the vertical movement is obtained by a rack and pinion.

ADJUSTMENTS.—These are made in the following order :—

(1) Focus the graticule with the eyepiece of telescope to suit the observer's sight.

(2) Focus the telescope until there is no parallax between a distant object and the graticule.

(3) Place the telescope in position on the base and set its axis in line with that of the collimator.

(4) Focus the collimator until there is no parallax between the image of its scale as seen in the telescope and the graticule of the telescope.

(5) Place the carriage in position with its front legs in the V on the base. Place the instrument to be tested and adjusted for parallel light on the carriage, and adjust it until one of the eyepieces is exactly opposite the lens of the collimator and the body is approximately horizontal. Set the telescope approximately opposite the objective of the binocular. Look in the telescope, and some part of the field of the collimator should be seen. Readjust until the centre of the field is level with the centre line of the graticule. Finally, rotate the binocular on the carriage until the centre of the field is also on the vertical line of the graticule.

(6) Read the magnification. If the image appears out of focus, the binocular is not properly focussed. It can be finally focussed while it lies in position, but it must again, if necessary, be adjusted to bring the centres of the fields of collimator and graticule coincident.

(7) Carefully slide the carriage along its V until the other eyepiece is opposite the collimator lens. If it is a Galilean instrument the telescope will still be in position; but if it is a prism-binocular, the telescope will also have to be moved slightly along its V.

(8) If the axes of the binocular are not parallel to one another, the centres of the fields will no longer coincide. The number of squares the image of the collimator field appears to have moved sideways and vertically measures directly the errors of the axes in these directions.

(9) Note if the field is twisted—shown by the horizontal lines no longer remaining horizontal. The amount of the twist can be read off, *e.g.*, if it drops 1 square in 20 it has twist of about 3°.

(10) Note if the image in the second position is out of focus; if so, the lenses are not correctly paired.

Telescopic Method for Determining the Principal Curvatures of a Nearly Flat Surface.

The light from an illuminated cross of which the arms are vertical and horizontal is incident at an angle of 45° on the surface to be examined, the plane of incidence being horizontal. The image is viewed in a telescope which is placed at a distance from the mirror equal to the focal length of its objective. If the surface is not a spherical one, it is rotated in its own plane until the image of one of the arms of the cross can be sharply focussed in the telescope—the principal curvatures of the surface will now be vertical and horizontal; the radii, r_1 and r_2, are given by

$$r_1 = \frac{\sqrt{2}\, f^2}{x_2}; \text{ and } r_2 = \frac{2\sqrt{2}\, f^2}{x_1};$$

where f is the focal length of the telescope objective, and x_1 is the amount the eyepiece of the telescope has to be moved from the standard position, when the cross is viewed by reflection in a plane mirror placed in the same position as the curved one, in order to focus the vertical arm of the cross when seen by reflection in the curved surface. x_2 is the corresponding measurement of the movement to obtain the image of the horizontal arm of the cross.

For, under the above conditions, the distances of the focal lines from the surface are given by

$$\frac{1}{v_1} + \frac{1}{u} = \frac{2}{r_2 \cos i}; \quad \frac{1}{v_2} + \frac{1}{u} = \frac{2 \cos i}{r_1}$$

where u is the distance of the cross from the mirror, v_1 is the distance of the vertical focal line, v_2 that of the horizontal one, r_1 and r_2 are the radii of curvatures of the vertical and horizontal meridians of the surface. Also the distances of the images of the cross as formed by the plane mirror, and of the images of these focal lines, formed by the curved mirror, from the second focal point of the telescope objective will be

$$\frac{f^2}{u}, \quad -\frac{f^2}{v_1}, \quad \text{and} \quad -\frac{f^2}{v};$$

so that

$$x_1 = \frac{f^2}{v_1} + \frac{f^2}{u} = \frac{2f^2}{r_2 \cos i} \text{ and } x_2 = \frac{f^2}{v_2} + \frac{f^2}{u} = \frac{2 \cos i f^2}{r}$$

where cos i is $\frac{1}{\sqrt{2}}$

G. CUSSONS, LTD.

Dioptriemeter.

This instrument, designed by Profs. W. W. Haldane Gee and A. Adamson, and based on the principle of Guilloz's focometer, is used for lens testing.

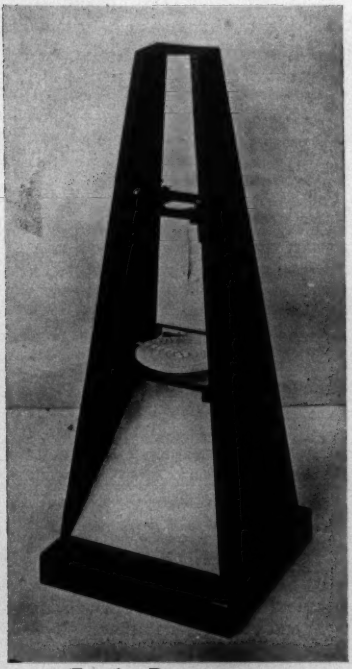


FIG. 9.—DIOPTRIEMETER.

It comprises a wooden framework, Fig. 9, having two shelves. On the lower shelf is fixed a horizontal card marked with a series of concentric circles 1 mm. apart, the radius of the innermost circle being 5 mm. and that of the outermost 30 mm.

The other shelf, which is of thin metal and has a circular aperture of 10 mm. radius, is supported exactly 100 mm. above the card. A thin sheet of metal having a central pinhole is fixed on the top of the frame exactly 200 mm. above the card.

The centre of the circular opening is indicated by cross wires, and the centre of the concentric circles is marked by a cross. These two centres and the pinhole lie on the vertical axis of the instrument.

When the eye is placed close to the pinhole, the field of view, limited by the circular aperture, will include all the circles up to that of 20 mm. radius. This circle is called the zero circle, and is marked O. The other circles are numbered consecutively, those within the zero circle being marked +, those outside it −.

The lens under measurement is placed in close contact with the metal shelf and is so adjusted that on looking through the pinhole the centres of the aperture and the circles are seen to coincide. The number of

circles now in the field of view, Fig. 10, depends upon the power of the lens, and the scale reading of the outer circle seen gives the value of the power of the lens in dioptres. To facilitate the estimation of the fractions of a dioptre, a portion of the disc at one side of the aperture is cut away, so as to expose a portion of the circles which would otherwise be hidden, and a fine wire is stretched across the gap at the place where the readings must be taken. In Fig. 10 the value is seen to be + 7.8 D.

An important use of the instrument is for the testing of cylindrical and sphero-cylindrical lenses. When such lenses are used, the circles appear distorted into curves somewhat resembling ellipses. The power of the lens in any one plane and meridian can be determined by observing

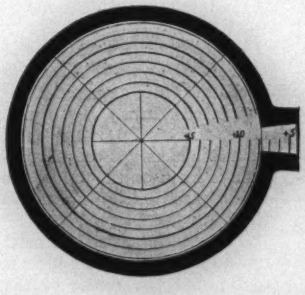


FIG. 10.—SCALE OF DIOPTRIEMETER SEEN THROUGH A CONVEX SPHERICAL LENS.

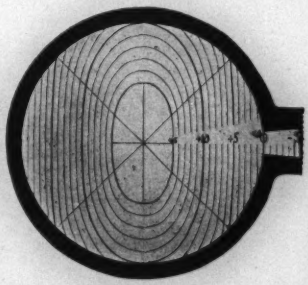


FIG. 11.— SCALE OF DIOPTRIEMETER SEEN THROUGH A CONVEX CYLINDRICAL LENS.

the scale number of the elliptical figure which intersects the sighting wire at the side of the field, Fig. 11.

The angle of minimum deviation caused by a thin prism or wedge can be found by the Dioptriemeter, and thence its power (prism-dioptres).

Irregularities in the curvature of a lens can be localised by means of the instrument, since they will cause distortion of the circles.

For further details see " Memoirs and Proceedings of the Manchester Literary and Philosophical Society " (Session 1910-11), Vol. LV, pt. 3.

EDISON & SWAN UNITED ELECTRIC LIGHT CO.

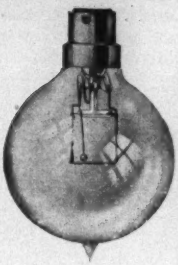


FIG. 12.

Pointolite Lamp.

The lamp consists of a clear, spherical bulb, gas filled, and containing a small tungsten head mounted on a stem (Fig. 12). An arc is established between this head and an "ionizing" bar, giving an extremely concentrated light source of high candle-power and great steadiness. The light is such as to approach more nearly to daylight in composition than that of any other arc or glow lamp so far produced. By means of a stepped resistance the lamp is adapted for use on any commercial voltage from 100 to 250 volts, d.c.

ADAM HILGER, LTD.

New Apparatus and Process for the Finishing of Prisms and Lenses or Combinations of the Same.

The apparatus consists of a modification of the Michelson interferometer. A beam of light is passed through the optical element in such a way as to produce a series of interference fringes which constitute what may be called a contour map of imperfections. The workman can draw this map on one of the surfaces of the optical element and remove the superfluous material from the prominences by local polishing. The method produces good work whether the imperfections are due to inaccurate surfaces or non-homogeneous material.

For further details see "Optician," Vol. LII, April 13, 1917.

Examples of flat work were also exhibited.

HENRY HUGHES & SONS, LTD.

A Measuring Microscope for Workshop Purposes.

The instrument is designed to measure the curvatures and focal lengths of an optical system in which the latter does not exceed 50 cm.

The instrument, Fig. 13, consists of a measuring microscope A mounted on a vertical brass column B with a graduated scale C of 500 mm. and reading by a vernier to ·01 mm. Motion is obtained by turning the milled head M.

The microscope can be turned into a horizontal position as shown in Fig. 14 when used for measuring the curvature of tools. The microscope has a longitudinal travel of 200 mm. reading on a scale D by a

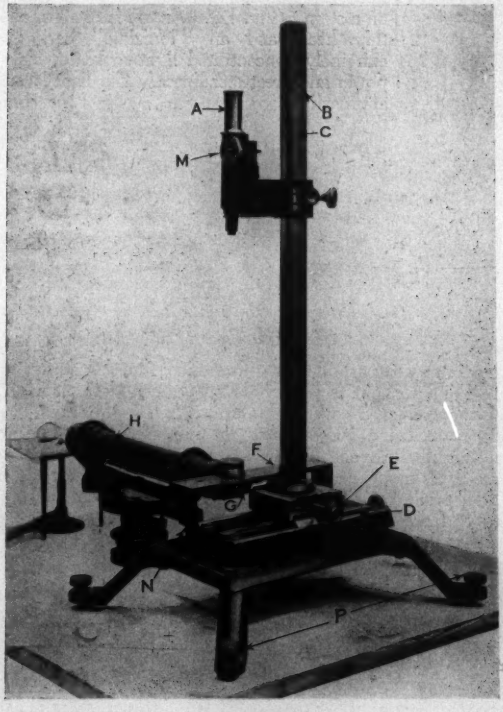


FIG. 13.

vernier to .01 mm. It has also a transverse adjustment by means of the milled head screw E. The brass stage F is adjusted to a horizontal position by the adjusting screw N, and then finally levelled by means

of the four levelling screws P. Light is reflected from a collimator H by means of a prism G in the stage of the instrument through the circular aperture L. The angle of the prism can be adjusted by means of the knob K, which is raised or depressed as required. Before using the instrument, it is necessary to see that the collimator is carefully levelled.

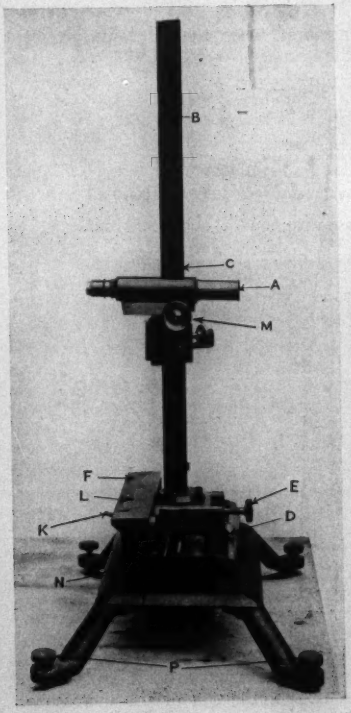


FIG. 14.

For comparing the curvatures of two surfaces, a scale is fitted over the eyepiece A. It is preferable to use monochromatic sodium light.

The following are the measurements for which it was designed :—

Curvature of Convex Tools.

The tool is screwed on to an adapter so placed that the vertex of the tool can be focussed when the microscope is about the centre of its run. Having focussed the vertex of the tool, use the two motions of the microscope to follow round the edge of the tool. Bring the cross-wire on to the edge of tool and take a reading on the horizontal scale. Then traverse the microscope and take a reading on the other edge.

The difference between these two is the length of chord. In a similar way the sagitta is measured, and the usual spherometer formula gives the curvature of the tool.

To Measure the Focal Length.

Carefully level the stage of instrument. Mount a collimator at right angles to the reflecting prism in stage of microscope and use as an illuminant a sodium flame. Place the objective in its cell on the stage and

an image of the crosswire of the collimator will be formed at its back-focal point. Secondly, focus on the back surface of the O.G. and thirdly, on the aperture in the stage. By means of the horizontal motion bring the crosswires on to the opposite edges of the aperture. Then if V_1, V_2, V_3 are the readings on the vertical scale, and H_1 and H_2 on the horizontal, the equivalent focal length $= (V_1 - V_2)\frac{a}{H_1 - H_2}$ where a is the diameter of the aperture.

Eye lenses can be similarly measured when the third measurement can be made on the back face of the lens

$$\text{and focal length} = V_1 - V_3$$
$$\text{back focal length} = V_1 - V_2$$

The complete eyepiece can also be measured.

Shallow Curves Measured by Newton's Rings.

By shallow curves are meant those with a radius above 500 mm.

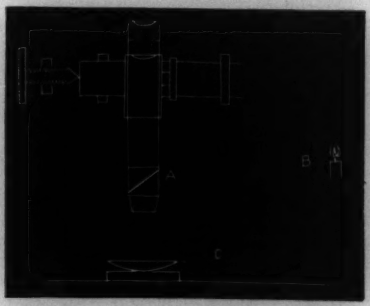


FIG. 15.—DIAGRAM OF ARRANGEMENT. A—REFLECTOR. B—SOURCE OF LIGHT. C—TEST SURFACE.

The microscope is fitted with a vertical illuminator, and a sodium flame illuminant is used. If the curve to be measured is convex it is placed on a plane plate so that the point of contact is on the axis of the microscope. The microscope is then focussed on the ring system and the diameters of the 1st and say the 18th ring are measured.

$$\text{Then } r = \frac{C_2^2 - C_1^2}{17 \times \cdot 0005894}$$

where C_1 and C_2 are the radii of the rings. A 1" objective is used for observing.

The method is easily adapted to the measurement of a shallow concave curve. It is also especially adapted to the measurement of differences of curvature.

The Measurement of the Curvature of Small Lenses.

By using the target shown in Fig. 5 the curvature of small lenses or tools can be measured as described on page 5 S by S. D. Chalmers, M.A.

Connolly's Focometer.

For details see Trans. Opt. Soc., Vol. XVIII, March, 1917, p. 62.

PROFESSOR H. JACKSON.

The Pulfrich Refractometer.

This instrument is used for determining the refractive index and dispersion of transparent fluid and solid bodies.

The fluid is placed in the short glass cylinder under S, Fig. 16. If a solid is to be experimented upon it must have two plane surfaces at right angles to each other, and one of these surfaces must rest on the prism contained in the mount L, in place of the glass cylinder. Light passes horizontally through the fluid or solid and enters at grazing incidence the right-angled flint prism contained in L. For sodium light the reflection prism N, on the surface of which is cemented a convex lens, is used. The flame is placed behind the prism N. For the hydrogen lines the Geissler tube Q and condenser P are used, while the prism N is rotated round the column M. The border line of total reflection is adjusted upon the point of intersection of the reticule in the telescope F E, which is rigidly connected with the rotatable divided circle D.

From the reading of the angle i on the divided circle the refractive index n_D is obtained with the aid of a table, from the formula

$$n = \sqrt{N^2 - \sin^2 i}.$$

The dispersion is measured by means of a micrometer arrangement This consists of the axial screw H, the measuring screw G with divided index and the drum and drum divisions. Direct readings can be taken in degrees and minutes of the angular distances between the border lines. The instrument can also be used to investigate fluids at high temperatures, and also as a differential refractometer.

For further details see "Zeitschrift für Instrumentenkunde," 1895, p. 389; "The Astrophysical Journal," Vol. III, No. 4, April, 1896, p. 259.

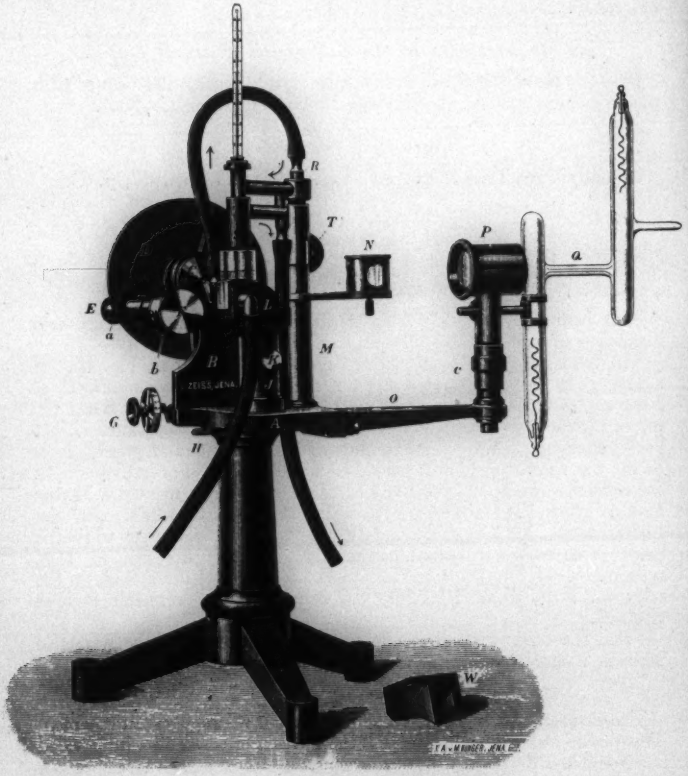


FIG. 16.—PULFRICH REFRACTOMETER.

Weathering Test on Glass.

The prisms or other samples under test are subjected for two hours to treatment in an autoclave at a pressure of two atmospheres, over distilled water containing the amount of CO_2 which it would normally absorb on being left to stand for a few hours. The autoclave temperature should be 130° to 135° C. The condition of the glass surface after this test is an index of the behaviour of the glass when subjected to normal atmospheric exposure.

L. C. MARTIN, A.R.C.Sc.

Apparatus for Determination of Refractive Index by Immersion.

It is suitable for lenses or rough pieces of glass which have no plane surface. Briefly described the procedure is to immerse the specimen in a liquid contained in a prism cell having walls of plane parallel glass; the liquid being a solution of potassium mercuric iodide or a mixture of alcohol and carbon disulphide. By observing a line spectrum produced by the cell with a spectrometer, the refractive index of the liquid may be made equal to that of the specimen by observing the focus of any particular line while the strength of the solution is varied. Mechanical stirring of the liquid is the salient feature of the method; this produces the necessary optical homogeneity.

Refractive indices may thus be determined to an accuracy of one unit in the fourth decimal place for most forms of test specimen except such as approximate to a plane parallel plate.

For further details see Trans. Opt. Soc., Dec. 1916.

NATIONAL PHYSICAL LABORATORY.

Apparatus for the Commercial Testing of the Refractive Properties of Optical Glass.

The refractometer is of the Pulfrich type, made by Zeiss.

The principal features of the auxiliary apparatus consist of the means employed for obtaining a hydrogen spectrum of suitable brilliance in all required lines (C, F and G^1).

One method is to employ a vacuum tube of large volume, 1½ litres approximately. This diminishes the rate of deterioration of the spectrum to something of the order of 1/70 of that of an ordinary small H tube.

(See Proc. Physical Soc., XXVIII, p. 60). A bulb tube with a stand suitable for use with the refractometer is shown in Fig. 17.

The method which has been found to be most generally convenient where there is a very large amount of testing to be done is to keep the vacuum tube in permanent connection with a small oil pump and an electrolytic hydrogen generator. By flushing the tube with gas (to wash out any air which has leaked in at the various joints) and re-exhausting, before testing each specimen, what is virtually a new tube is obtained for each test. This allows the use of heavier discharges, giving greater brightness of the spectrum lines, than can be employed with a small sealed-off tube. The advantage of this in testing certain glasses is very great.

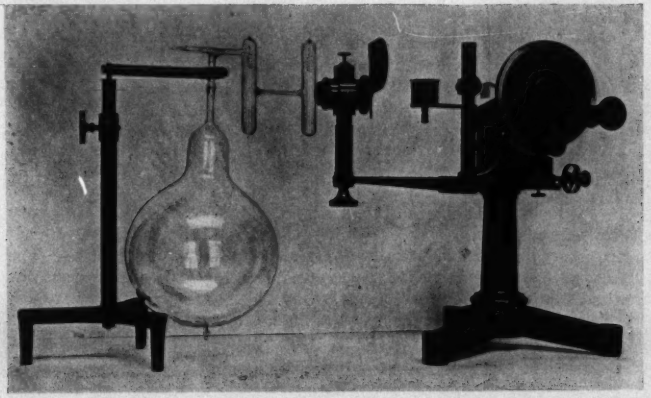


FIG. 17.—PULFRICH REFRACTOMETER AND BULB TUBE.

The hydrogen generator, which is of a simple type readily constructed in any workshop is shown diagramatically in Fig. 18. A bell jar, B, which may consist of a "Winchester" bottle with the bottom removed, sits inside a suitable containing vessel, V, preferably, but not necessarily, of glass. The stopper employed should be of rubber, in which case it is not necessary to wax it over. A disc, D, of nickel gauze is jammed into the jar about 2 inches from the bottom end and a nickel wire is led from it through the insulating glass tube G. A strip, N, of nickel gauze is bound round the outside of the jar and forms the other electrode. The

electrolyte employed is a strong solution of washing soda. To fill the jar with hydrogen, the taps T_1 and T_2 are both opened and the pump is slowly worked. The liquid is allowed to rise up to the neck of the jar and T_1 is closed. The wires, W W, are then connected directly to a supply of 20 to 30 volts, the inner electrode being connected to the negative pole of the battery. If a larger voltage is employed, a resistance must be inserted to reduce the current to 4 or 5 amps. When the liquid in the jar is driven down below the electrode D, the circuit is broken and the

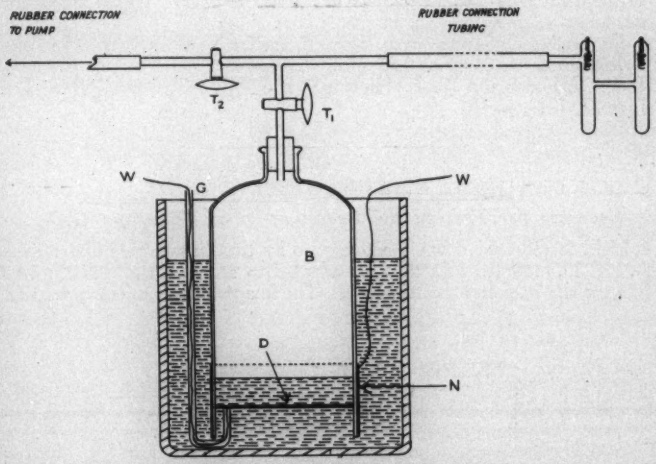


FIG. 18.—HYDROGEN GENERATOR.

current ceases. The arrangement is automatic and the voltage is left permanently connected. There is thus no danger of the generator being found empty when required. Before testing a specimen the tap T_2 is closed and T_1 is opened. This fills the vacuum tube and connecting tubing with hydrogen at approximately atmospheric pressure. T_1 is then closed and T_2 opened. The expansion into the pump reduces the pressure to 3 or 4 cm. of mercury, and a few strokes of the pump completes the evacuation to the required extent. The whole arrangement is very simple in practice and can always be relied on.

The complete test of the refractive indices of a satisfactory specimen to 1 or 2 units in the fifth decimal place, for four wave lengths, only occupies from 10 to 15 minutes inclusive of the time spent in preparing the tube in each case.

Luminosity Tests of Radium Painted Dials.

The apparatus exhibited is that employed at the National Physical Laboratory for carrying out tests of the luminosity of dials painted with Radium Luminous Compound. The method is virtually a comparison of the dial under test with a pair of " artificial dials " whose luminosity can be varied as desired until a match is obtained.

For further details see Proc. Physical Soc., XXIX, 1917, p. 215 : " An Investigation on Radium Luminous Compound " by C. C. Paterson, J. W. T. Walsh and W. F. Higgins ; and " The Optician," Vol. LIII, June 22, 1917, p. 199.

OPTICAL DEPARTMENT, MINISTRY OF MUNITIONS.

Eyepiece for Testing the Squaring-on of Telescope O.G.s.

Light is reflected down the telescope by the diagonal annular mirror A, Fig. 19, mounted in a tube B, adapted to screw in the ordinary way into the draw-tube of the telescope. The images of this mirror produced

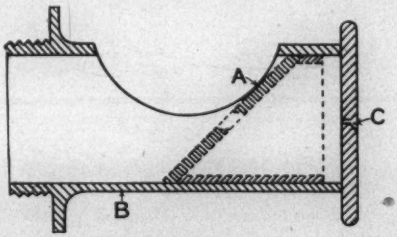


FIG. 19.

by the different curved surfaces of the lenses, and seen as circular annuli, are viewed by looking down the telescope through a pin-hole C at the end of the tube, the O.G. being covered by a cloth or cap during the operation. The O.G. is adjusted until these images are seen to be concentrically disposed about the line of sight, *i.e.*, the axis of the telescope.

Microscope Focometer.

This apparatus is designed for measuring the focal lengths of lenses up to about 4 inches, either positive or negative. A collimator is fitted to the under side of the stage of a simple microscope stand, Fig. 20. This collimator is fitted in its lower focal plane with a glass scale upon which two lines are drawn a millimetre apart. These lines are crossed at the middle of their lengths by another line at right angles to them. In the upper focal plane of the collimator, and in the plane of the upper surface of the stage, a disc is fitted with a narrow diametral slit which is arranged in the direction parallel to the two parallel lines of the lower scale. This slit serves to secure telecentric adjustment and at the same time facilitates the focussing of the scale. (For a fuller explanation see the Journal of the Royal Microscopical Society 1914, pp. 513-519). The lens to be measured may be placed upon the stage of the microscope, and the size of the image of the scale projected by it is measured by an auxiliary microscope mounted in the draw-tube. Each division of an eyepiece scale (1 cm. divided into hundredths) in this auxiliary microscope is made equivalent to one millimetre of focal length, so that the latter is read off directly. The optical dimensions of the focometer may be such as to give to one division of the eyepiece scale any desired equivalent of focal length. The focometric collimator used in this apparatus may be made to different scales and used on the optical bench in combination with a

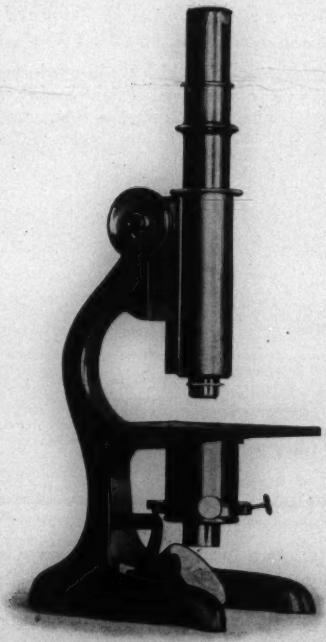


FIG. 20.

micrometer eyepiece for focometric determinations generally. The greatest accuracy is obtained by adjusting the slitted disc in the principal focal plane of the lens to be tested and then measuring the distance apart of the two images of the millimetre scale in the other focal plane by means of the micrometer eyepiece.

Focometer for Measuring Back Focal Lengths as designed by Zeiss (see British Patent Specification 12100-1914).

Figure 21 shows one form of the apparatus in which the lens to be tested is placed in a standardised position in a parallel beam of light issuing from a collimator fitted with cross-wires. The beam from the lens, whether

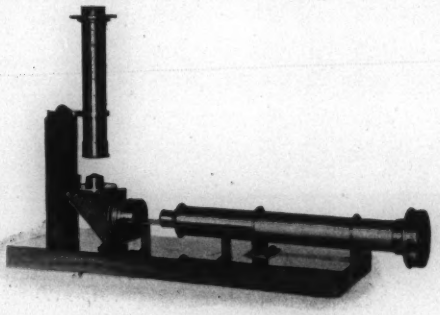


FIG. 21.—FOCOMETER.

converging or diverging, is brought to a focus by a fixed positive lens. The focal length is determined from the displacement of the final image of the cross-wires produced by the introduction of the lens being tested.

A metre scale A, Fig. 22, carries at one end a disc B with a vertical slit in it. A cross-bar C, sliding on the scale, has on its inner face, opposite to the slitted disc, two vertical cross lines DD at a given distance apart, crossed near their middle by a longitudinal line E at right angles. The lens L to be tested is placed so that the slitted disc occurs in one of its focal planes. The desired focal length is obtained by measuring with an eyepiece micrometer scale M or in any other way, the separation S of the two images of the vertical lines DD carried by the cross-bar. This arrangement is probably the simplest and most reliable for workshop use.

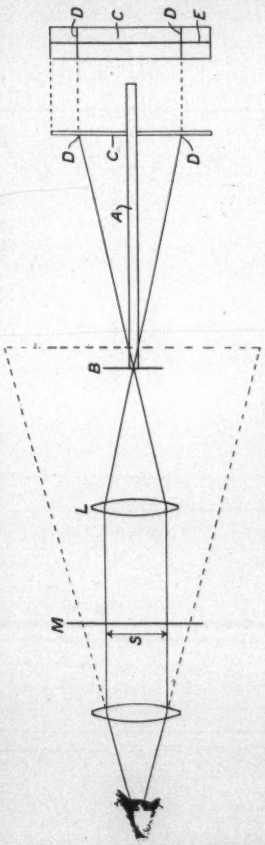


FIG. 22.

The metre scale with its slitted disc and sliding cross-bar may be looked upon as a substitute for a collimator and has the advantage of being free from aberration. (See the article in the Journal of the Royal Microscopical Society quoted above).

Apparatus for Testing Parallax in Telescopic Sights for Rifles.

In the ordinary tests of sighting telescopes for parallax, the eye of the observer is moved to and fro laterally. This method is not satisfactory because it leaves too much to individual judgment. In the apparatus exhibited an artificial eye has in effect been substituted. In the exit pupil of the telescope being tested a brass plate with a hole of about 4 millimetres diameter is arranged. This plate is arranged to slide backwards and forwards through a short distance across the axis of the telescope being tested, to simulate the movement of the pupil of the eye in the ordinary test for parallax. Behind this artificial pupil the telescope is mounted with two vertical lines in its focal plane. As the artificial pupil is slidden from one side to the other, any displacement of the image of the vertical sighting line in the telescope being tested should not carry it outside the two vertical lines. The distance apart of these two lines is determined by the parallactic tolerance.

Testing Parallelism in Prismatic Binoculars.

A pair of collimators are mounted so that their axes of collimation are parallel to one another, and also to that of an observing telescope which

can be moved parallel to itself to and fro across the direction of collimation. The binoculars to be tested are adjusted between the

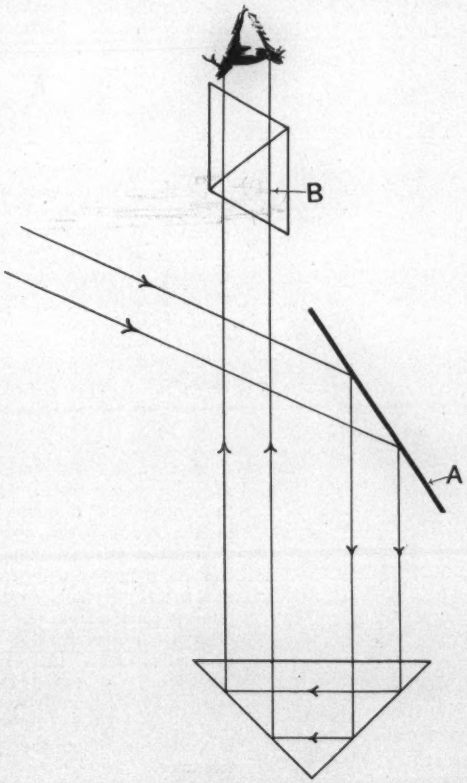


FIG. 23.

observing telescope and the collimators until the cross-wires of one of the collimators are projected on to the cross-wires of the observing telescope.

The latter is then moved across to the second component of the binocular and the displacement of the projected image of the second collimator wires is then measured off by comparison with the cross-wires of the observing telescope.

Polariscope.

In applying polarising tests to optical glass, especially in the form of prisms, it is always desirable, if possible, so to arrange the test that the light passes through the prisms in the same direction as that in which it passes when in use in the instrument. This instrument, which is a modification of the well-known Bennett doubler, has been designed to allow of the testing of right-angle prisms in this way. Polarised light is reflected vertically down by a plate of glass, A, Fig. 23, coated at the back with black French polish. This light enters the prism to be tested, and after being twice reflected, as shown, it passes upwards through an analyser B to the eye of the observer.

A. W. PENROSE & CO., LTD.

Spectroscopic Camera.

Designed by ALEX. A. K. TALLENT.

Constructed by A. W. PENROSE & CO., LTD.

The idea in view in designing this Spectroscopic Camera has been to provide an apparatus which, whilst being as efficient as the much more elaborate forms of laboratory spectroscopes hitherto used, is small, light, compact, handy and inexpensive. The important advantage is that it is ready for use at any instant without any fixing together or adjustment of parts.

The compact form of the camera has been rendered possible by the use of a Thorp Diffraction Prism Grating (F in Fig. 24). This grating is a replica of a very perfect Rowland Grating ruled on speculum metal with approximately 14,500 lines to the inch. The spectrum of the first order which is employed is particularly bright. The grating is mounted between two achromatic lenses E and G, the former acting as a collimator and the latter as a projecting lens. One has about half the focal length of the other, and they are placed at distances from the slit and from the plate approximately equal to their focal lengths.

The slit D is of a special pattern, the movable jaw being adjusted by sliding on an inclined plane. The motion is large in proportion to the slit opening, and, therefore, greater accuracy in setting the width of the slit is obtained. A scale is engraved to show the extent of the opening

in tenths of a millimetre. For special work a Hilger slit with wedge of black glass can be used, this giving intensity curves directly on the photograph.

A holder B is provided for colour filters, flat cells of solution and other transparent objects.

The lens A acts as a condenser, and its distance can be adjusted by drawing out the base. The parts H and K are for trapping stray light.

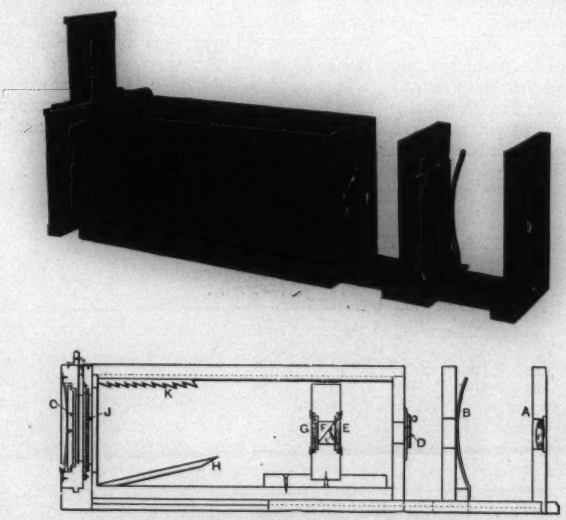


FIG. 24.—SPECTROSCOPIC CAMERA.

A wave-length scale can be placed in the position J and brought into contact with the plate.

The dark slide C runs in a groove so that it may be moved along to obtain a succession of four or five spectra on the same plate. A pointer indicates the correct position for each exposure.

A ground glass frame is provided for visual examination, but no focussing is required, the camera being permanently set to the correct focus.

Quartz Spectrographic Apparatus.

Constructed by A. W. PENROSE & CO., LTD., under the advice of R. S. CLAY, D.Sc.

This apparatus was specially constructed for making spectrographic tests where it is important that ultra-violet light should not be absorbed, as it would be in the usual apparatus with glass prisms and lenses.

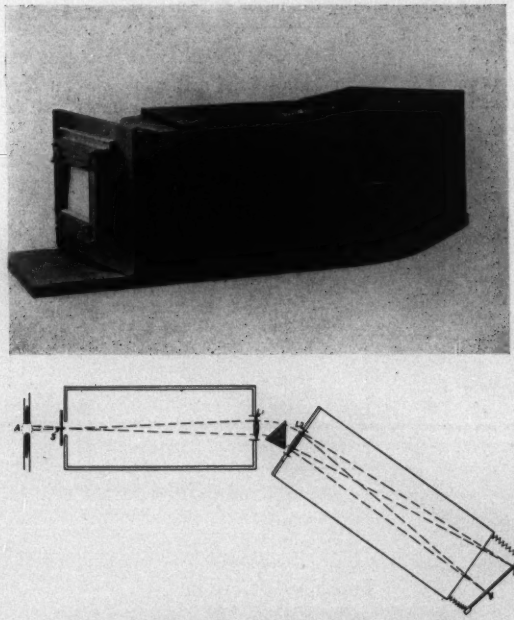


FIG. 25.—QUARTZ SPECTROGRAPHIC APPARATUS.

Accordingly, the present apparatus is fitted with a quartz prism Q and quartz lenses L_1 and L_2, L_1 being a collimating lens of about 12 in. focus, and L_2 a projecting lens of about 20 in. focus.

The back of the camera is made to incline in order that the violet end of the spectrum can be focussed nearer L_2 than the red end of the spectrum. The back carries a ground glass screen and a photographic dark slide, the latter being arranged so that a series of exposures can be made on the same plate by steps. The slit is adjustable, and there is an indicator to show the amount of separation of its edges. The illumination is by means of the incandescent gases between the electrodes of an electric arc lamp, for which iron electrodes may be used, or carbon electrodes charged with sodium chloride or other salt, the salt being inserted in a hole drilled in the lower carbon.

RAPHAEL'S, LTD.

Optical Bench.

This Bench, Fig. 26, is made of solid mahogany, two metres long and graduated in mms. With the outfit are six metal bases with stems, and adjusting screws to regulate height and centre.

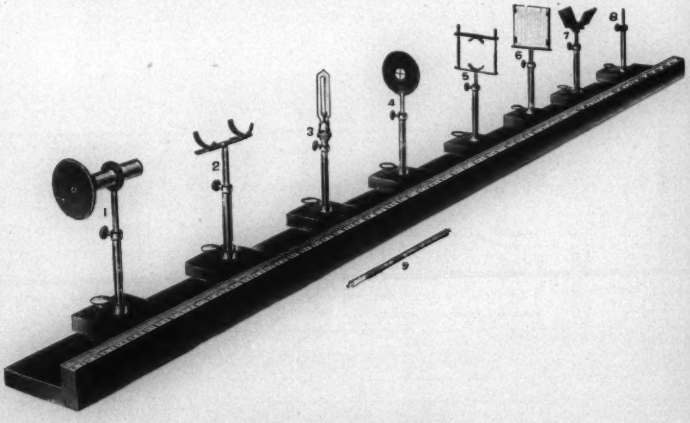


FIG. 26.—OPTICAL BENCH.

(1) Collimator, with achromatic object glass.
(2) Double Lens Holder.
(3) Lamp Holder.
(4) Screen with cross wires.
(5) Universal Lens Holder.
(6) Focussing Screen.
(7) Nodal Point Fitting.
(8) Telescope with cross wires, and achromatic object glass and Huyghenian Eyepiece.
(9) Standard Rod.

Lens Measure.

An instrument designed to measure the dioptric power of spherical and cylindrical lenses, such as are used in spectacle work.

This instrument is made in watch form suitable for carrying in the pocket.

ROSS, LTD.

Large Polariscope for Testing Optical Glass for Internal Strain and Determining the Presence of Striae.

The method of testing for strain is based upon the fact that glass under tension shows a degree of double refraction when brought between crossed nicol prisms. The intensity of the double refraction forms a guide as to the amount of strain present in any piece of optical glass. As no glass shows absolute freedom from strain, it becomes necessary to adopt an arbitrary standard for the amount of double refraction that may be allowed in optical glass. A good method is to select, as standard, a piece of a melting known to

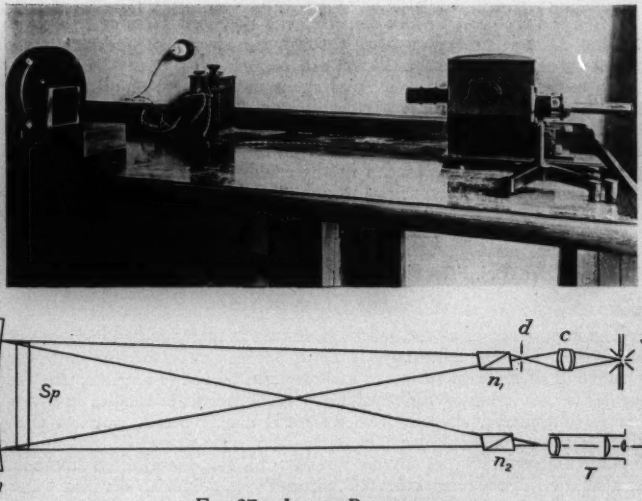


FIG. 27.—LARGE POLARISCOPE.

be sufficiently free from strain for the best class of optical work and to examine the standard simultaneously with the test piece. Both have to be well polished and fairly plane parallel to give the best result obtainable from the instrument.

The light from a strong source *S* Fig. 27 (electric arc or point of light) passes through a condenser *c* and is brought to a focus in the plane of a small diaphragm *d*. This may be variable in size to suit the amount of double refraction present in any specimen under test. From the diaphragm the light passes through a nicol prism n_1 of suitable size to a concave glass mirror *m*, the surface of which is only polished and not silvered. The reflected light passes through a second nicol prism n_2, and a small telescope *T* into the eye of the observer. The plate of optical glass *Sp* to be examined is placed beside the standard in front of the concave reflecting surface. The light emanating from the diaphragm must be divergent to a degree to fill the whole mirror, and since the diaphragm is placed at a distance from the mirror of twice its focal length, a conjugate image will be formed on the surface of the second nicol prism when the same is placed at an equal distance away from the mirror. The object of the small telescope, which is focussed upon the test piece, is to magnify the same 3 to 4 times, purely for convenience of observation.

From the sketch it will be seen that the polarized beam of light from the first nicol prism passes twice through the glass disk under test, and thereby greatly increases the efficiency of the method.

To combine the test for internal strain in any piece of glass with an examination for the presence of striae it is only necessary to employ a very small aperture in the diaphragm to obtain as nearly as possible a point source of light and to turn one nicol prism from its crossed position to the parallel one. Any imperfection in the specimen examined will then be clearly discernible by observing through the telescope.

WM. SHACKLETON, F.R.A.S., A.R.C.Sc.

Silvering Glass Mirrors.

The importance of a good reflecting surface in many optical instruments is obvious, and the advantage of the deposition process over the older practice of silvering by means of mercury and tin foil is so great, that the former is now in almost universal use. The elements of success in silvering are cleanliness, absence from dust and a temperature not less than 70° F.; the work should be handled as little as possible.

After the surface to be silvered has been cleaned by whiting, ammonia or a solution of washing soda and thoroughly washed with distilled water it should be immersed in the silvering solution; the two most important

solutions are given below, the Rochelle salt being used when the work is required to be silvered on the back, as in looking glasses, and the "Brashear" when the deposit is required on the face, as in mirrors of telescopes, and where the glass can be suspended face downwards in the silvering solution.

Rochelle Salt Method.

Solution A: Silver nitrate, 5 grams; water, 40 c.c.

When dissolved add ammonia until precipitate is nearly redissolved. Dilute to 500 c.c. with distilled water, and filter.

Solution B: 1 gram silver nitrate is dissolved in a little water and added to 500 c.c. of boiling water. Add 0.83 grams Rochelle salt (sodium potassium tartrate). Boil for a few minutes (5—10) and filter hot.

The last of the ammonia must be added drop by drop, being very careful not to allow the precipitate to entirely dissolve. In case the latter occurs add a few drops of silver solution the same strength as the original until the colouration appears.

When ready to silver, use equal parts of A and B, place the glass in a shallow dish and pour over it the mixed solutions. Rock the dish gently until the silvering is nearly complete. Ten to twenty minutes are usually required for a good coat, but a second or third coat can be given, when it is best to use a weaker solution about half strength; the further applications should be hotter than the first and at a temperature of about 105 degrees F.

If the solutions are more than two or three weeks old they do not give a sufficient coating of silver. If, however, both solutions are warmed to 95 or 105 degrees F. and allowed to cool they will be found to deposit as well as fresh solutions.

This method is the best for semi-transparent films.

Brashear's Process.

In Brashear's process, the most important thing is the sugar solution forming the reducing agent. This greatly improves by keeping—a solution that has been made some months being much more effective than a newly-made one.

For convenience his proportions are slightly varied and given as found to work well. For the sugar solution add to a 10 per cent. solution of loaf-sugar, in distilled water, 10 per cent. of alcohol and ½ per cent. of nitric acid. Solutions of 10 per cent. of nitrate of silver and of caustic potash are separately prepared, the latter one as wanted. These, with sufficient ammonia and a very dilute solution of nitrate of silver, and also a similar very dilute one of ammonia, are prepared, the latter in order to obtain that pale brown colour of the ammoniated solution of nitrate of silver

that it is absolutely necessary to have before adding the reducing agent.

Having selected a suitable dish to contain the liquid, in which the mirror can be placed face downwards with about ½ or ¾ inch of liquid underneath, find, on the basis of 1 of silver-nitrate solution to 4 of the total required liquid, the amount of silver solution needed; to this add ammonia till the first formed precipitate is dissolved, then add one half of this quantity of the potash solution (this is a variation from Brashear's formula that works well), and again add ammonia till the mixed solution is quite clear, taking care to put in only sufficient ammonia for that purpose; then add the weak solution of nitrate of silver till a clear brown colour is obtained; should this become a dark brown, some of the weak solution of ammonia will bring it to a pale brown colour, which must persist if the solution is left standing some time.

The mirror, previously cleaned with nitric acid and distilled water, and suspended in the dish in distilled water of sufficient amount to make up on the addition of the solutions the total liquid required, is lifted out and the prepared solutions mixed with the distilled water and an amount of the reducing solution equal to about one half that of the nitrate of silver solution, more or less as the temperature is under or over 60°; as soon as all is intimately mixed the mirror is immersed with one movement, beginning by dipping the edge first and lowering so as to prevent any air-bubbles forming under the glass. In from three to five minutes the silver begins to form on the mirror, the solution changing from pink to dark brown and black, the film thickens quickly, and in from twenty-five to thirty minutes sufficient silver is deposited. The mirror can then be washed and put to soak in distilled water for a few hours, then taken out and dried and polished in the usual way, that is, with a soft pad of clean chamois, and going all over the mirror with light strokes till the bloom is all removed and a fair polish is obtained, finishing with a very little of the finest washed rouge, quite dry, lightly dusted on the pad; it is very important to consolidate well the film of silver by the unrouged pad before using any polishing-powder. (From "The Observatory," No. 193, 1892.)

The most important thing (after the solutions) is the proper cleansing of the glass, for on the proper preparation of the surface of the glass a very great deal depends.

As already stated, this process is used when the glass to be silvered can be suspended in the liquid; it is not suitable when we attempt to silver surfaces face upwards. The mud formed settles down and prevents any proper deposition of silver.

Some further details on Silvering Glass are to be found in "Astrophysical Journal," Vol. I, 1895, p. 252; "Nature," Sept. 23, 1897, p. 505; "English Mechanic," Feb. 3, 1911; "Knowledge," Nov. 1914, p. 402.

H. TINSLEY & CO.

Apparatus for Testing the Magnification, Field of View, and Illumination of Field Glasses or Small Telescopes.

Constructed to the designs of Dr. C. V. DRYSDALE.

It consists of a collimator C, Fig. 28, with translucent screen brightly illuminated by the lamp L and bearing a scale of divisions each corresponding to 1° of angle at the back nodal point of the O.G. In front of this is a camera or "artificial eye," E having a lens with 5 mm. aperture correspond-

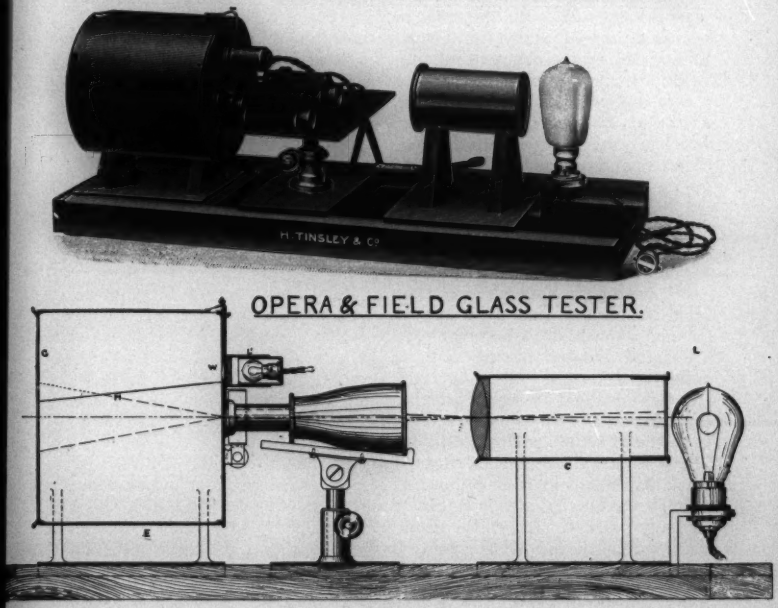


FIG. 28.

ing to the maximum normal diameter of the pupil of the eye, and a ground glass screen or "retina" G upon which a scale of degrees is also engraved. When nothing is interposed between the collimator and the eye, the

projected divisions of the former correspond with those of the latter, but if a telescope be placed between them, the projected divisions are enlarged and the magnification is directly given by the number of screen divisions corresponding to a projected division. The total angular field of view is given by the number of projected divisions in the illuminated field. In order to obtain the illumination, the camera is provided with a second variable aperture W, with a small glow lamp L' in front of it, which is in series with the main lamp. This illuminates a screened off portion of the "retina," and the lamp is adjusted so that when the aperture is a maximum the illumination from it just balances that from the collimator before the glass is interposed. On then placing the glass between them, the illumination is decreased, and it can be again balanced by reducing the aperture illuminated by the comparison lamp. The percentage illumination of the field for a 5mm. pupil is then approximately indicated by a pointer at the top of the camera. The test takes into account the loss of light both by absorption and reflection and by constriction of the beam, and gives a figure which represents the practical value of the illumination. The tests are all objective and can be seen by several persons at the same time.

For further details see Trans. Opt. Soc., 1902, p. 86.

Binocular Parallelism Tester.

For testing the Parallelism of the Axes (and the centering) of Binocular Field Glasses. This is a simple self-contained form of the double collimator device described by Dr. Drysdale at the Optical Convention of 1905, and adopted by the National Physical Laboratory. It has been designed for rapid testing and adjustment of binocular glasses to an accuracy of about .1 degree which is ample for practical purposes. The construction and principle are sufficiently seen from Fig. 29. The binoculars to be tested simply rest vertically upon a plate glass table which has screw adjustments for levelling in either direction, and the image of a cross or other diaphragm in each collimator tube is projected through them and through the lens L on to a screen S, and forms a single image if the axes are truly parallel. If not, the displacement of the axes is easily seen and measured, by the aid of the squares on the screen, each square representing 1 degree. A hinged mirror is fixed on the supports, and can be clamped at any angle so as to permit the screen to be seen directly in front of the observer. The centering of the lenses may be tested by turning them round in their mounts, and the magnifying power of the glass is indicated by the number of degrees which the image covers.

For further details see Trans. Opt. Convention, 1905, p. 143, "Small Telescopes and Binoculars."

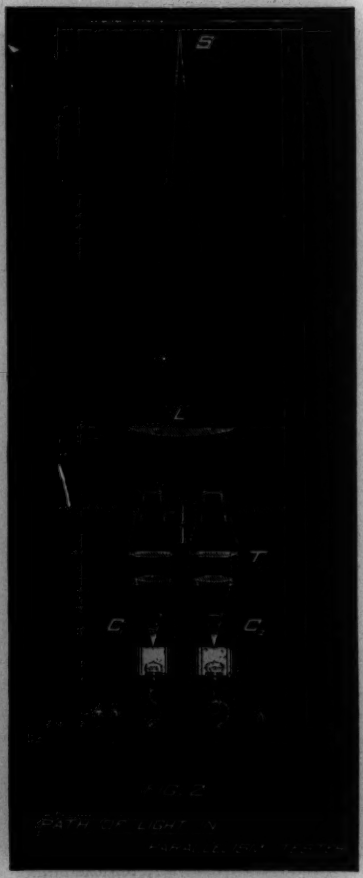


FIG. 29.
BINOCULAR PARALLELISM TESTER.

Definition Tester.

For observing the Aberrations of Microscopes, Telescopes or Photographic Lenses.

This simple little device consists of a small cap which clips over the eyepiece of any microscope or telescope. It contains a piece of plane parallel glass set at 45° to the axis, and has a lateral aperture through which

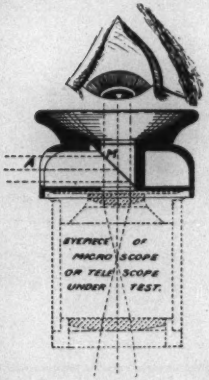


FIG. 30.—DEFINITION TESTER.

light from a distant small white or monochromatic source is reflected along the axis of the microscope or telescope under test. It is then reflected from a plane silvered mirror and passes back through the instrument to the observer's eye. The instrument is focussed so as to see the source as an artificial star, and on racking in or

out, the point of light expands into a disc, which exhibits chromatic or spherical aberration, astigmatism, etc. Coma is eliminated by the symmetry of the test, but the other defects are doubled in amount and are thus rendered more visible.

For further details see Trans. Opt. Soc., 1902, p. 100, "The Testing of Optical Instruments," by C. V. Drysdale.

TROUGHTON & SIMMS, LTD.

Micrometer Theodolite.

This instrument is used for surveying where great accuracy is required in reading vertical and horizontal angles. The circles are divided to 10 minutes of arc, while the graduations on the micrometer head are equivalent to 10 seconds, and readings to 1 second can be obtained by estimation.

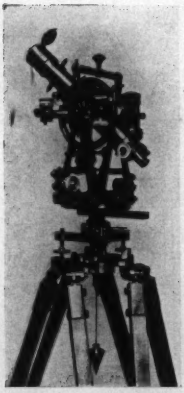


FIG. 31.—MICROMETER THEODOLITE.

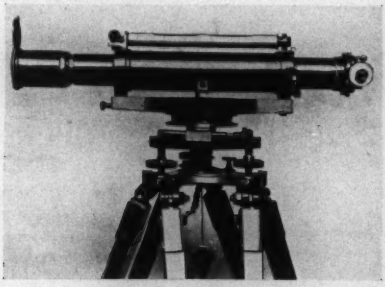


FIG. 32.—REVERSIBLE LEVEL WITH MICROMETER EYEPIECE.

UNI-BIFOCAL CO., LTD.

Micrometers for measuring the angles of prisms before polishing.

Telescope and artificial star for optically testing the definition of prisms.

Test object for estimating the pyramidal error of prisms.

Light source, black glass polariser and Nicol analyser, for examining strain in finished prisms.

W. WATSON & SONS, LTD.

Glass Discs as Primary Standards of Curvature.

The old method of depending on metal discs and rings turned to the diameter of the curve to be produced is not at all reliable when great accuracy is demanded, and the spherometer, especially in the form usually found in Glass Shops, is little if any better. The glass discs exhibited (a number are shown in Fig. 33) are a great advance in accuracy on either method. They really represent the equatorial segment of a polished glass sphere and would seem to be the most accurate possible means of fixing

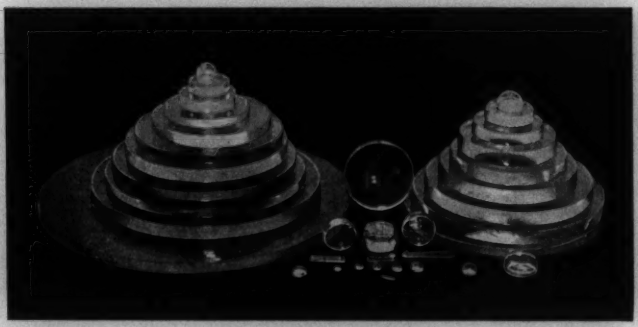


FIG. 33.—GLASS DISCS.

a curvature, firstly because the full diameter of the sphere can be directly measured, and secondly because the concave test plate can be directly fitted to the curve thus measured with the utmost accuracy by the Newton's rings method.

Prism Testing Machine.

This machine, which depends on a combination of a sensitive magnifying lever and microscopic observation, is shown in Fig. 34. The prism to be tested is accurately located upon a geometrical fivepoint bearing formed by polished steel balls, three of which arranged in triangular configuration definitely locate the horizontal face of the prism, whilst the other two balls bear on the lower part of the vertical face. A rounded point of the short arm of the sensitive lever is brought to bear by spring pressure on the extremity of the vertical face of the prism. The finely pointed upper end

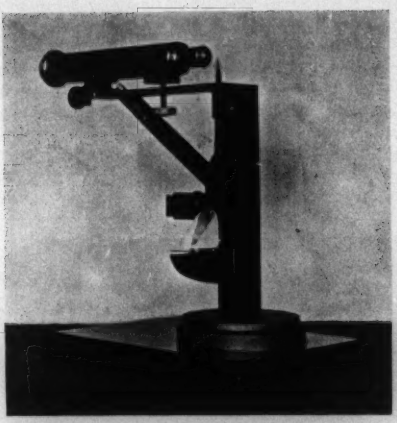


FIG. 34.—PRISM TESTING MACHINE.

of the lever then takes up a position depending on the angle of the prism placed in the machine, and this position is observed by a microscope with a micrometer eyepiece, each division of which indicates a change in angle of about 20 seconds of arc. The standardisation of the machine is also done on strict geometrical principles, for a prismatic glass block is used for this purpose which has four perfectly flat faces approximately at right angles to each other. Obviously the *mean of these four angles* must be precisely 90° whatever the errors of the individual angles might be.

Micrometer for Measuring the Separation of Microscope Lenses.

The performance of Micro-objectives depends not only on the accurate curvature and thickness of the constituent lenses, but also in an almost equal degree on their correct separation. The little contrivance shown at the left of Fig. 35 enables this separation to be measured with the full accuracy of the Brown & Sharpe micrometer head. It will be at once obvious from the figure how the instrument works, the lens to be measured being screwed into a collar in the base of the instrument and the ball-pointed micrometer screw being brought down in succession to the several upper surfaces of the lenses. The separation of these upper surfaces then follows directly by taking differences of the readings.

Micrometer for Measuring the Thickness of Large Lenses.

This instrument is shown at the right hand side of Fig. 35, and is simply the adaptation of the remarkably accurate Brown & Sharpe micrometer head to a very much enlarged U shaped bow, which allows the reaching of the centre of large lenses.

Ring Spherometer.

The old-established three-legged form of spherometer suffers from the drawbacks of this instrument in a particularly high degree, as it is almost impossible to determine accurately, or to maintain unchanged, the diameter of the circle on which the instrument makes contact with the surface being measured. The instrument shown in the centre of Fig. 35

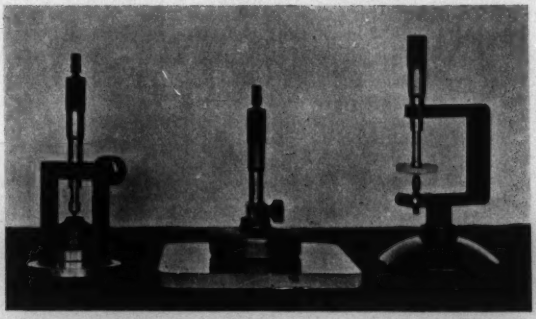


FIG. 35.—MICROMETER FOR MEASURING THE SEPARATION OF MICROSCOPE LENSES.

diminishes this difficulty by taking its bearing on a complete circular edge of a hardened steel ring which obviously can be more easily and more accurately measured, and is also less subject to rapid wear. The measuring screw is once more represented by a Brown & Sharpe micrometer head.

Apparatus for Rapid Comparisons of Focal Lengths.

This is quite a crude apparatus, which nevertheless produces results of great accuracy with considerable rapidity. The machine is shown in Fig. 36 and depends on the measurement of the minimum distance between object and image, and the rapidity of its action is secured by having a fixed holder for the lens to be tested at the centre of the machine, and having the frames holding the object at one end and the receiving screen at the other move simultaneously in opposite directions by racks actuated by a central pinion attached to the hand wheel at the centre. When

the central lens carrier has once been adjusted for a particular type of lens, it is obvious that other lenses of the same type can be read off in rapid succession.

FIG. 36.—APPARATUS FOR RAPID COMPARISONS OF FOCAL LENGTHS.

Determination of Curvature of Polished Surfaces by the Microscope.

This depends on the well-known fact that a reflecting spherical surface has two positions in which object and image coincide, the one being when the object is in contact with the surface, and the other when the object is at the centre of curvature of the surface. In this instrument the object for the purpose of this measurement is represented by the image of a lamp reflected downwards into the microscope by a transparent reflector at 45° placed above the eyepiece. The measurement of the curvature is obtained by measuring the distance through which the instrument has to be focussed to pass from one of the images mentioned to the other. The advantages of this method are that it can be applied to small and irregular fragments of polished surfaces, and that the results for the radii of curvature are generally dependable to well within 1-10th of a mm.

The "Naked Eye" Test for ight-Angle Prisms by the "Optical Square" Image.

For details see Trans. Opt. Soc., Vol. XVI, p. 181.

WOOLWICH INSPECTION DEPARTMENT (D.I.O.S.).

Piece of Scale for Testing Angles.

This scale, which is shown in Fig. 37, is made of well-seasoned wood, painted black. The graduations consist of thin sheets of white celluloid inserted edgewise in saw cuts in the wood. This form of scale is not liable to become indistinct through exposure to the elements; the white graduations remain white over a long period of time, and in the event of their becoming dirty their whiteness is easily restored by scraping the surface.

Such scales would be used at a distance of from 50 to 100 yards from the instrument which is being tested.

Simple Instrument for Testing the Sensitiveness of Bubbles.

The instrument, Fig. 38, for testing sensitiveness of bubbles consists of a bar about 12 in. long, pivoted at the end *A* and having a micrometer screw *B* at the other; the point of this screw rests on an adjustable pillar *C*. The adjustable pillar is capable of being raised or lowered; it enables the bubble under test to be set centrally without altering the reading on the disc. The micrometer screw has a fine thread and carries a large disc *D*, which is graduated in minutes with subdivisions of 15 seconds, and fractions of this may be estimated if required.

A "V" shaped holder *E* is mounted on the top of the bar and is pivoted at *F* and *G*, so that it is capable of rotating about the axis *F G*. A "rolling" movement may thus be given; stops are inserted so that this movement does not exceed 10° to either side. A fork-shaped guide *H* is planted at the micrometer end of the bar, and the whole is mounted on a solid metal base, supported on three adjustable screws.

To test the value of a division on the bubble scale, the zero on the disc *D* is set opposite the pointer *J*, and the milled nut *C* under the disc is turned till the bubble is in the centre of its run. By turning the disc "right" or "left" till the air-bubble has moved through one division, the value of this division may be read off the disc.

The test for "roll" is carried out by rotating the holder *E* about the axis *F G*.

Machine for Testing and Adjusting the Parallelism of Binoculars.

The machine, Fig. 39, consists essentially of the following parts:—

(1) Base *A*.
(2) Double collimators *B* and *C*.
(3) Telescope *D*.
(4) Adjustable Y bracket *E*.

FIG. 37.—PIECE OF SCALE FOR TESTING ANGLES.

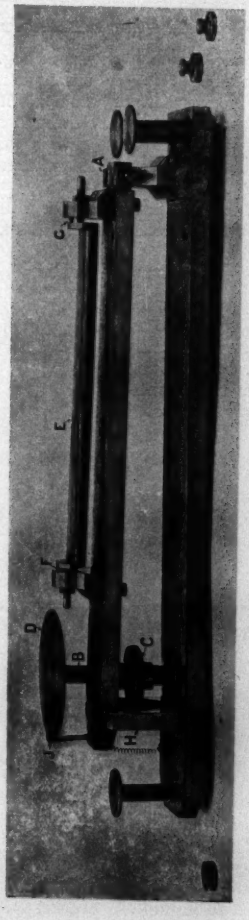


FIG. 38.—INSTRUMENT FOR TESTING THE SENSITIVENESS OF BUBBLES.

The double collimator consists of two tubes rigidly fixed together. Each has an object glass fixed at the one end, the other end being filled in by a piece of ground glass. Into each tube there is fitted in the focal plane of the object glass a glass diaphragm which can be adjusted by four capstan-headed screws. The diaphragm in the right collimator has four lines on it which intersect, forming a rectangle. The diaphragm in the left collimator has two lines at right angles to one another forming a cross. The rectangle above mentioned indicates the limits of error allowed in the parallelism adjustment. The testing telescope is an inverting one with cross-wires placed in the focal plane. It is capable of being raised or lowered to suit binoculars of different sizes. Its base is fitted carefully in a guide so that the intersection of the cross-wires shall move accurately in a horizontal plane and at right angles to the axes of the collimators. The eyepiece has an adjustable focussing arrangement.

The adjustable Y bracket, on which the binocular to be tested or adjusted is placed, is provided with fine lateral and vertical adjustments. These are actuated by two milled heads on the right and left of the bracket. There is also an arrangement fitted for approximate lateral setting. This is effected by loosening the milled head at the top front of the bracket, pushing over the binocular support in the required direction and fixing by tightening up the nut.

To Adjust the Instrument.—Focus the cross-wires in the telescope and adjust the latter so that when looking through it the wires are coincident with the cross-lines on the diaphragm of the left collimator. These latter cross-lines should also be in focus without any parallax.

Slide the telescope in front of the right collimator. If its cross-wires do not intersect in the centre of the four lines on the collimator diaphragm, this diaphragm requires to be adjusted by means of the capstan-headed screws. When these adjustments have been made, they should not be altered during the test of a binocular.

To Test and Adjust a Binocular.—Place the binocular on the Y bracket and focus the cross-wire in the telescope, then focus the binoculars so that the magnified cross-lines are clearly seen in the telescope. When this is so the binocular is focussed for infinity. Adjust the tilting table till the cross-wires of collimator and telescope are coincident. Slide the telescope until it is in front of the right collimator. If the intersection of the cross-wires in the telescope falls within the rectangle on the collimator diaphragm, the binocular is in adjustment; if not, it requires to be adjusted. This test should be applied for different interocular extensions.

If the binocular requires adjustment, it should be revolved on the Y bracket. If either side is correctly collimated, the cross-lines will not

appear to shift in the process. In general both sides will require adjustment, and that side which shows the greatest amount of swing should be approximately adjusted to the more correct side and so on until the final adjustment is completed.

The instrument, which is carried in a box, is compactly made for use at the Front, and the adjustments can be easily tested. It has been designed by the D.I.O.S. Inspection Department in conjunction with the Ordnance College.

Iron Plate for Testing Definition and Colour Correction.

This consists of an iron plate, painted black, with round, square and triangular holes of various sizes in it. It enables the definition and colour correction of binoculars, telescopes and other instruments to be tested. The size of the holes selected depends upon the distance at which the plate is to be used and also upon the magnification of the instrument under test, so that plates of this nature can be used at any distance provided the

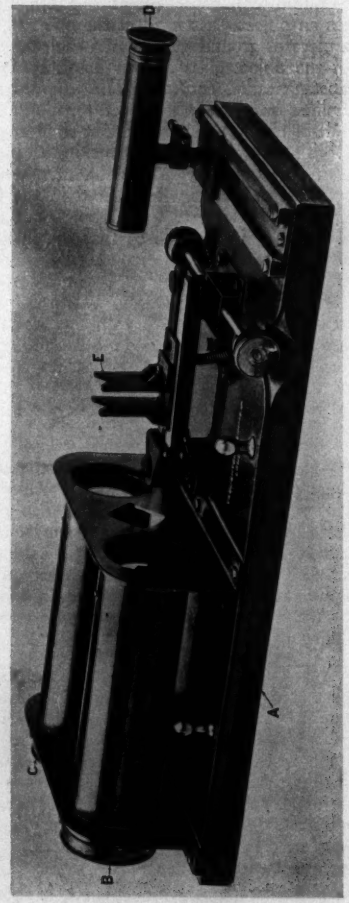


FIG. 39.—MACHINE FOR TESTING AND ADJUSTING THE PARALLELISM OF BINOCULARS.

perforations represent very small angular measurements in the *apparent* field.

In using the plate for testing *definition*, the plate is viewed through a telescope or binocular focussed for the centre of the field. If the definition is satisfactory, all the perforations in the plate should then appear sharp, well defined and free from distortion.

In the case of *colour correction* an instrument properly corrected should show the holes in the plate without any appearance of colour in any part of the field. Defective colour correction will be shown by the appearance of a "rainbow-like" fringe round the edges of the holes, while defective centering is shown by different colours on the two sides. With a given magnification, the smaller the holes the more severe the test.

Digester for Testing the Suitability of Glass to Withstand Atmospheric Deterioration.

Prisms or other pieces of glass are suspended in the apparatus by silver wire and are subjected gradually to the action of steam at an ultimate temperature of 130° C, or about 40 lbs. per square inch pressure, for about two hours. A glass capable of withstanding atmospheric influences should show no signs of a film on its surface or pitting after the conclusion of the test.

Polariscope for Testing Strain in the Prisms of a Binocular.

Polarised light obtained by reflection from a black glass plate or a pile of clear glass plates is passed through the binocular and viewed by means of a Nicol prism. In order to show the effect of strain as clearly as possible the light passing through the binocular is reflected at an angle of about 57° (the polarising angle).

If a prism has been strained in the adjustment, and the Nicol is revolved, the strain produced in the glass is very distinctly evidenced by a marked variation in the intensity of the emergent light in different parts of the field.

The apparatus Fig. 40, consists of a pile of glass plates *A* and a holder *B* for the binocular. This holder carries a slide fitted with a Nicol prism *C* by which the polarised light transmitted through the binocular is analysed. A lens is also provided for use with the Nicol. The holder is arranged so that when the binocular rests on it, the light passing through it is inclined at an angle of 57° to the normal to the plate. Thus angle *D E F* is $33° = (90° - 57°)$. By the interposition of a piece of mica the effect is rendered more distinct, as shades of colour or different colours instead of black and white are seen, the colours varying as the Nicol is turned.

The apparatus is easily made, simple to work and not too sensitive for the purpose.

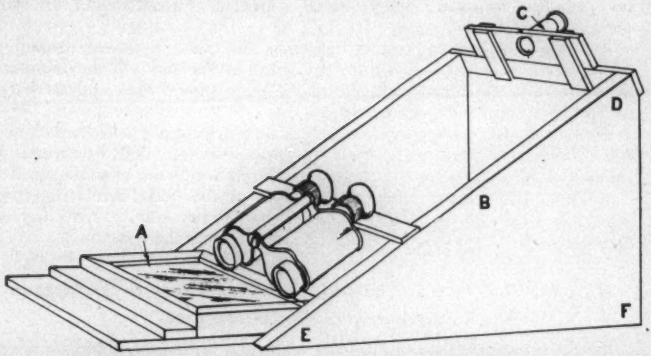


FIG. 40.—POLARISCOPE FOR TESTING STRAIN IN THE PRISM OF A BINOCULAR.

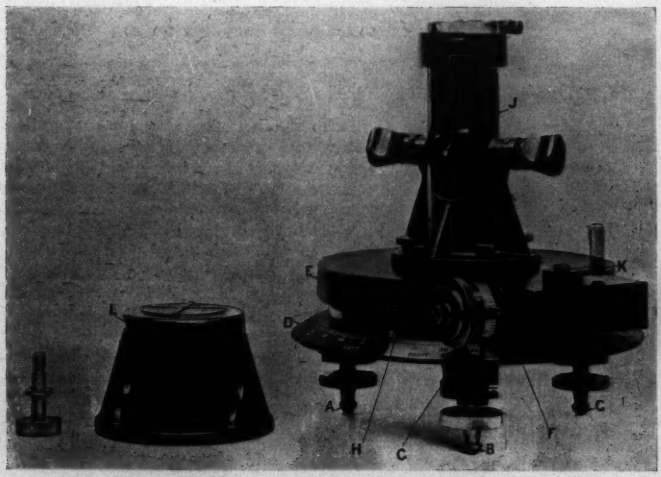


FIG. 41.—APPARATUS FOR TESTING AZIMUTH ANGLES.

Apparatus for Testing Azimuth Angles.

This machine (Fig. 41,) designed by the Director of Inspection of Optical Stores, Inspection Department, consists of a gunmetal tripod fitted with three levelling screws *A B C*, a worm wheel and a movable scale plate *D* graduated in degrees from 0° to 180° right and left. On the top of this is pivoted a plate *E* fitted with a worm spindle *F* and a micrometer drum *G* to read to minutes; the reader plate *H* for reading degrees is also attached to this plate. On the top of this plate various adapters may be fitted. The one *J* shown in position in the figure is suitable for holding a No. 7 Dial Sight, and the one *L* at the side is for a No. 5 Director. The adapter *J* may be removed by unscrewing the screws securing it, and other adapters may be substituted. The machine is supplied with a cam *K* for engaging and disengaging the worm spindle, and also a milled screw for clamping the graduated ring.

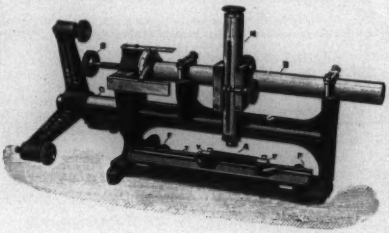
To Use the Machine.—The machine is set upon three shoes and levelled by means of a bubble placed on the top of the adapter. The instrument under test is then inserted in the adapter and all scales on it and the machine are set to zero. (If the independent traversing gear in the instrument or adapter has not sufficient movement, the cross-wires in the instrument can be laid on the distant point by means of the traversing gear of the machine, and the graduated ring and skin of the micrometer drum of the latter can be set at zero by loosening their clamping screws and turning them.) The cross-wire in the instrument is then laid on a distant point or the intersection of two cross-lines in a collimator. This is done by means of independent traversing gear in the instrument or adapter.

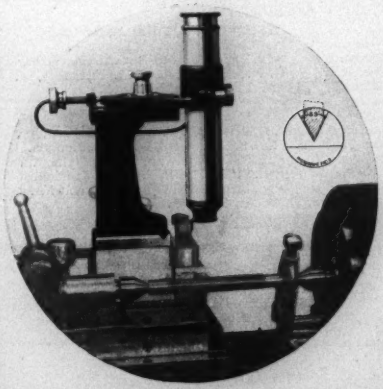
The machine is now set at any desired angle and the instrument under test is set at the same angle in the opposite direction. The cross-line of the instrument should then be on the distant mark. If it is not, the micrometer drum is turned until coincidence with the distant mark is obtained and the error read off on the micrometer drum.

CAMBRIDGE INSTRUMENTS.

MEASURING MICROSCOPE

for the measurement of lengths to 0·001 mm. and of angles to 5′ of arc. Suitable for measuring pitch and angle of screws.





MICROSCOPE LATHE ATTACHMENT.

This attachment is designed for mounting on a lathe to enable the tool to be set for precision screw cutting.

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Further particulars of either of the above instruments will be sent on request.

THE CAMBRIDGE SCIENTIFIC INSTRUMENT CO. LTD.

CAMBRIDGE, ENGLAND.

BRITISH OPTICAL ASSOCIATION.

INCORPORATED 1895.

Objects of the Association.

(1.) The encouragement of (*a*) the science of optics and (*b*) the art of the application of the science of optics to the improvement of human vision.

(2.) The protection of the Members of the Association from influences inimical to the prosperity of the profession of an optician.

(3.) The doing of all such other lawful things as are incidental or conducive to the attainment of the above objects, provided that the Association shall not impose on its Members or support with its funds any regulation or object which, if an object of the Association, would make it a trade union.

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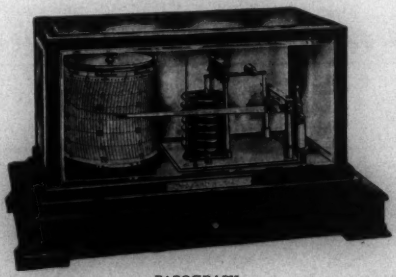

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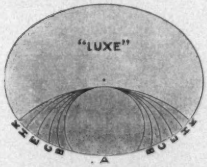

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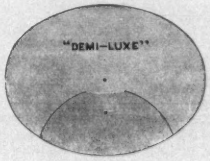

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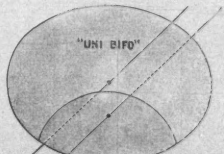

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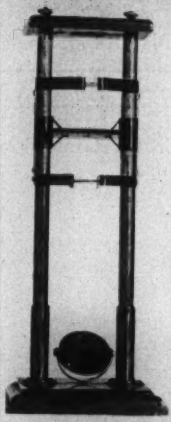

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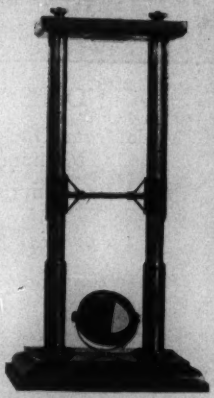

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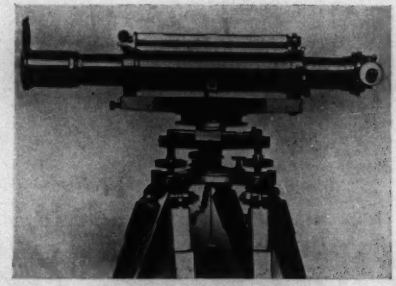

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